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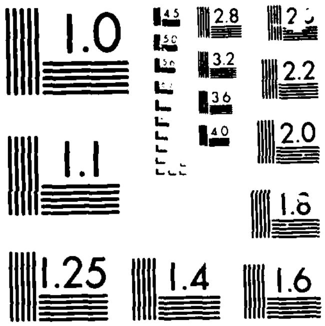
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INTEGRATED REFRACTIVE EFFECTS PREDICTION SYSTEM (IREPS), INTERIM USER'S MANUAL

H. V. Hitney and R. A. Paulus

March 1979

Interim Report: July 1978 — February 1979

Prepared for
Naval Air Systems Command

NAVAL OCEAN SYSTEMS CENTER
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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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This document is an interim user's manual for the Integrated Refractive Effects Prediction System (IREPS). To provide a theoretical background for users of the system, electro-magnetic (EM) wave propagation in the lower atmosphere is reviewed in terms of naval radar, communications, and electronic warfare system performance. A discussion of surface-based ducts, elevated ducts, and evaporation ducts is included. Also included, is a survey of some tactical applications of atmospheric ducting to naval warfare. The operation portion of this document describes the IREPS. This provides a detailed description of the various IREPS products and how they are used to define optimum propagation conditions for a given EM system.

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CONTENTS

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this manual is to introduce the reader to a variety of effects that the lower atmosphere (troposphere) has on the performance of many naval electromagnetic (EM) systems and to describe the use of the Interim Integrated Refractive Effects Prediction System (IREPS), based on the Hewlett-Packard HP9845. The effects of concern here are only significant at EM frequencies above 100 MHz; and therefore, capable of affecting radar, uhf and microwave communications, electronic warfare, and missile guidance systems. The effects that the ionosphere has on hf communications or other systems is specifically not included in this document.

1.2 THE IREPS CONCEPT

IREPS is a system undergoing research and development at NOSC, which will ultimately result in a shipboard environmental data processing and display system to assess refractive effects of the lower atmosphere for naval EM systems. IREPS will eventually feature full militarized hardware and software in its final form, but will not be available for several years. Also, IREPS may be combined with the shipboard version of the Naval Environmental Display Station (NEDS II), to form a Shipboard Environmental Support Center (SESC). Since any final hardware configuration of IREPS or SESC is several years away, an Interim IREPS based on a Hewlett-Packard model 9845 desktop calculator has been developed which will give early limited operational capability aboard CV/CVNs. It will also provide early interaction of laboratory and operational personnel to further define and develop refractive effects assessment capabilities.

IREPS has been developed, and is continuing to be refined at NOSC, to give a comprehensive refractive effects assessment capability for naval surveillance, communications, electronic warfare, and weapons guidance systems. IREPS has been successfully used under operational conditions aboard selected CV/CVNs to assess and exploit refractive effects in tactical situations. The Interim IREPS unit should give each operational CV/CVN a capability that has never before existed.

Prior to describing the operation of the Interim IREPS, a background of refractive effects, its causes, and resulting benefits or detriments to naval EM systems will be presented (Section 2.0).

2.0 BACKGROUND

2.1 WHAT ARE REFRACTIVE EFFECTS?

The term "refractive effects" refers to the property of a medium (here, the lower atmosphere) to refract or bend an EM wave as it passes through the medium. In this document, the term is taken to imply a wider meaning which includes all propagation effects of, or related to, the lower atmosphere that affect the performance of EM systems. As such, the term includes not only refraction and ducting, but also reflection from the sea surface, multipath interference, diffraction around the earth's surface, tropospheric scattering, sea clutter, and many other propagation mechanisms or processes. For most naval EM systems, the occurrence of ducting in the troposphere provides the most dramatic impact on system performance.

2.1.1 Ducting and Refraction

The term "ducting," as used in this document, means the concentration of radio (or radar) waves in the lowest part of the troposphere in regions characterized by rapid vertical changes in air temperature and/or humidity. Such atmospheric ducts are very analogous to the ducts encountered in ocean acoustic propagation resulting from vertical changes in pressure, temperature, and salinity in the ocean. "Surface ducting" means such concentration of radar waves immediately adjacent to the sea surface. To understand these concepts, a knowledge of the bending, or refraction, of radar waves in the atmosphere will be required. The refractive index, n, of a parcel of air is defined as the ratio of the velocity of propagation of an electromagnetic (e.g. radar) wave in vacuum to that in the air. Since electromagnetic waves travel slightly slower in air than in a vacuum, the refractive index is slightly greater than unity. At the earth's surface, the numeric value of the refractive index n is usually between 1.000250 and 1.000400. In order to have a number that is easier to handle, the refractivity N has been defined to be $N = (n - 1) \times 10^6$, such that surface values of refractivity N vary between 250 and 400. Refractivity can be expressed as a function of atmospheric pressure, temperature, and humidity by the relation:

$$N = \frac{77.6P}{T} + \frac{3.73 \times 10^5 e}{T^2}, \qquad (1)$$

where

P is atmospheric pressure in millibars,

T is temperature in Kelvins, and

e is water vapor pressure in millibars.

For a well-mixed "standard" atmosphere, both temperature and humidity decrease with altitude, such that N decreases with height at a rate of about 39 N units per 1000 metres (or 12 N units per 1000 ft). The behavior of an EM wave propagating horizontal to the earth's surface is such that it will bend or "refract" toward the region of higher refractivity (lower velocity). For the standard atmosphere, a radar wave will bend down toward the earth's surface, but with a curvature less than the earth's, as illustrated in figure 1. If, however, the air temperature increases with altitude or the humidity decreases abnormally fast with altitude, then N will decrease with height much faster than normal. If N decreases

faster than 157 N units per 1000 metres (48 N units per 1000 ft), then a radar wave will refract downwards with a curvature exceeding the earth's curvature and a surface duct will be formed, as illustrated by the example in figure 2. Note that, while the radar wave refracts towards the sea surface, it reflects or "bounces" upward from the sea in this example. It is the continuous refracting down and reflecting up that forms the surface duct and allows for surface detections far beyond the normal horizon.

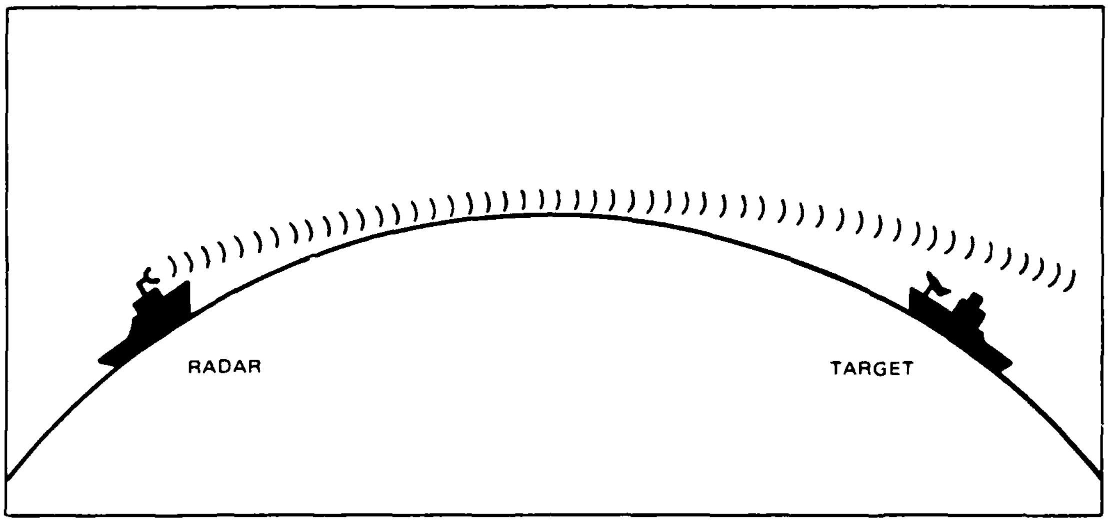


Figure 1. Radar wave path under "standard" atmospheric conditions. Note path curves downward but at a rate less than the earth's curvature. Beyond-the-horizon target detection is not possible.

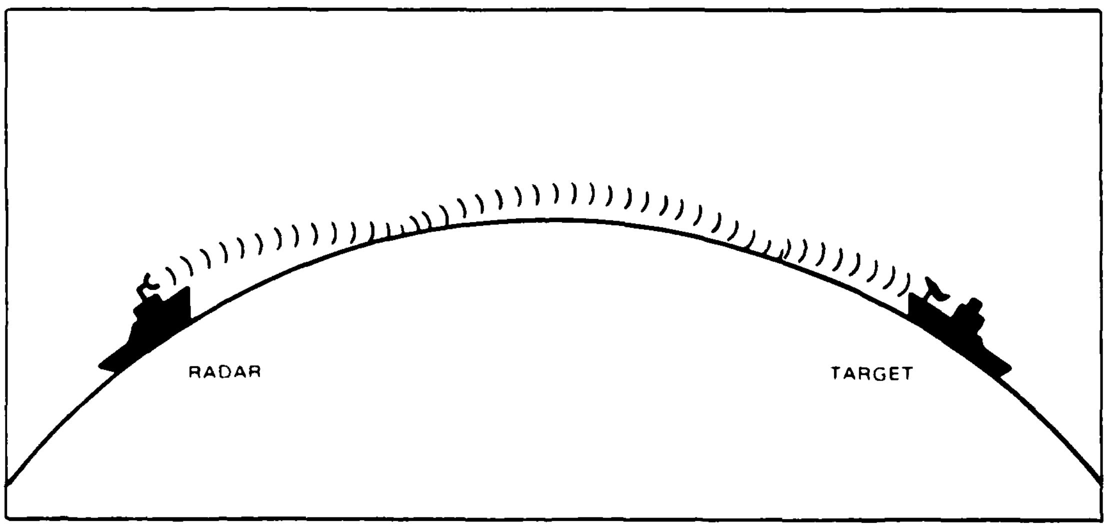


Figure 2. Radar wave path under ducting conditions. Path curves downward at a rate exceeding the earth's curvature resulting in beyond-the-horizon target detection.

As a convenience in determining the occurrence of ducting, the modified refractivity M has been developed. M is related to N by

$$M = N + 0.157\ h \text{ for altitude h in metres, or} \qquad (2)$$

$$M = N + 0.048\ h \text{ for altitude h in feet.}$$

The modified refractivity takes into account the curvature of the earth in such a way that the presence of ducting can be determined from a simple inspection of M plotted versus height. Whenever M decreases with height, a so-called trapping layer is formed wherein an EM wave can be refracted towards the earth's surface, thus forming a duct. Figure 3 shows N and M plotted versus height for a standard atmosphere, and figure 4 shows N and M plotted versus height for one type of surface ducting condition, illustrating the concept.

In figure 3, M constantly increases with height; hence, there is no trapping layer or resulting duct formed. In figure 4, M decreases with height in one region and thus forms a trapping layer. If the M value at the top of the trapping layer is less than the M value at the surface, then a surface-based duct will be formed in the height interval indicated by the dashed vertical line in figure 4. If the M value at the top of the trapping layer is greater than the M value at the surface, then a so-called elevated duct will be formed as indicated in figure 5.

Besides trapping, there are three other terms that describe the vertical gradient or change with height of N and M; namely superrefractive, standard, and subrefractive. Superrefractive implies an N gradient that is stronger than the normally expected or standard gradient, but *not strong enough to form trapping*. Subrefractive implies an N-gradient weaker than the standard gradient which results in less refraction or bending than normal. Figure 6 graphically shows the relative amounts of bending for each of the four types of refraction. Table 1 shows the definition of these four types of refraction in terms of the N- and M-gradients.

Table 1. Relation of N- and M-gradients

	N-Gradient	M-Gradient
Trapping	$\leqslant$ -157 N/km	$\leqslant$ 0 M/km
	$\leqslant$ -48 N/kft	$\leqslant$ 0 M/kft
Superrefractive	-157 to -79 N/km	0 to 79 M/km
	-48 to -24 N/kft	0 to 24 M/kft
Standard	-79 to 0 N/km	79 to 157 M/km
	-24 to 0 N/kft	24 to 48 M/kft
Subrefractive	> 0 N/km	> 48 M/km
	> 0 N/kft	> 157 M/kft

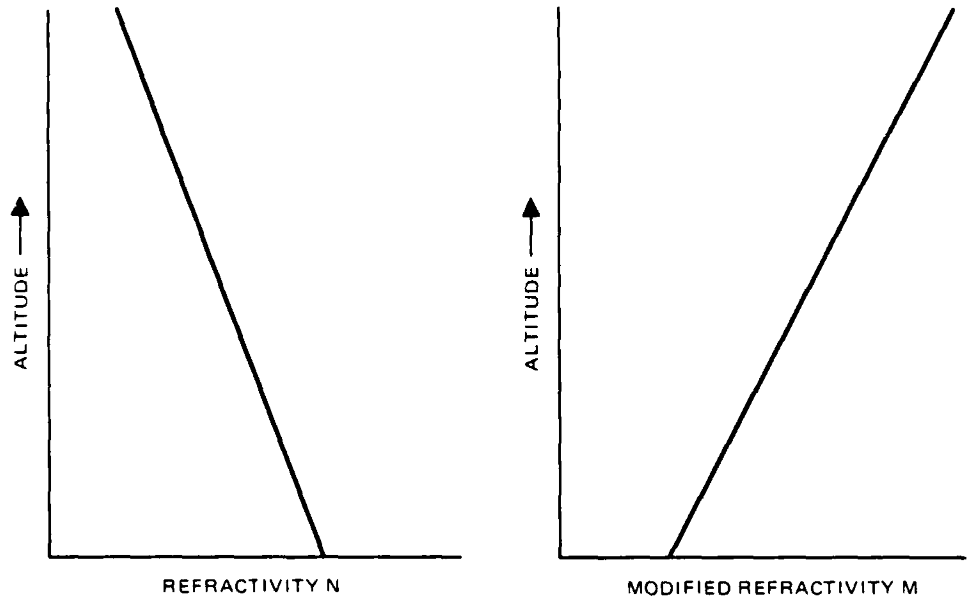


Figure 3. Refractivity N and modified refractivity M versus altitude for a standard atmosphere.

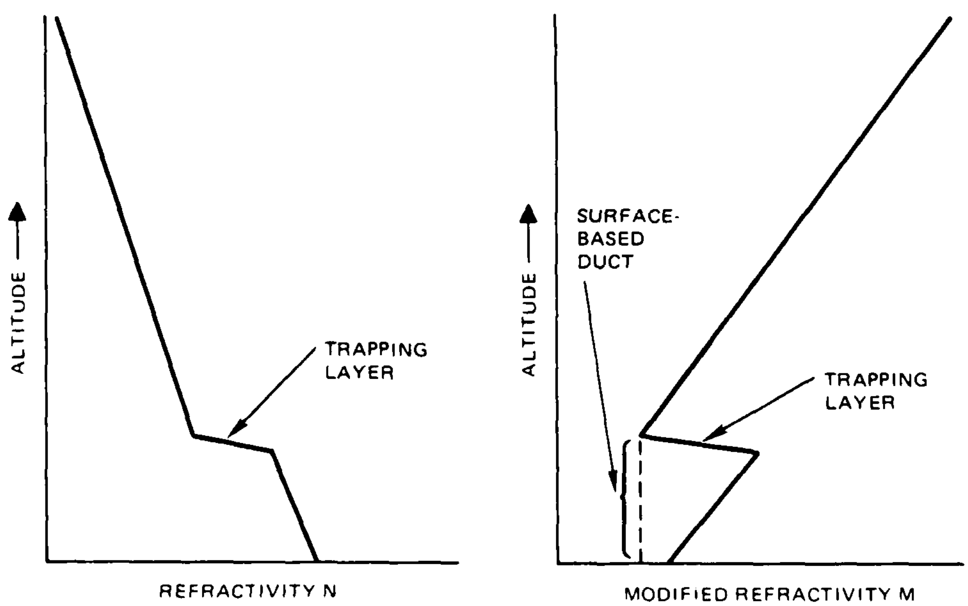


Figure 4. Refractivity N and modified refractivity M versus altitude for a surface-based duct created by an elevated trapping layer.

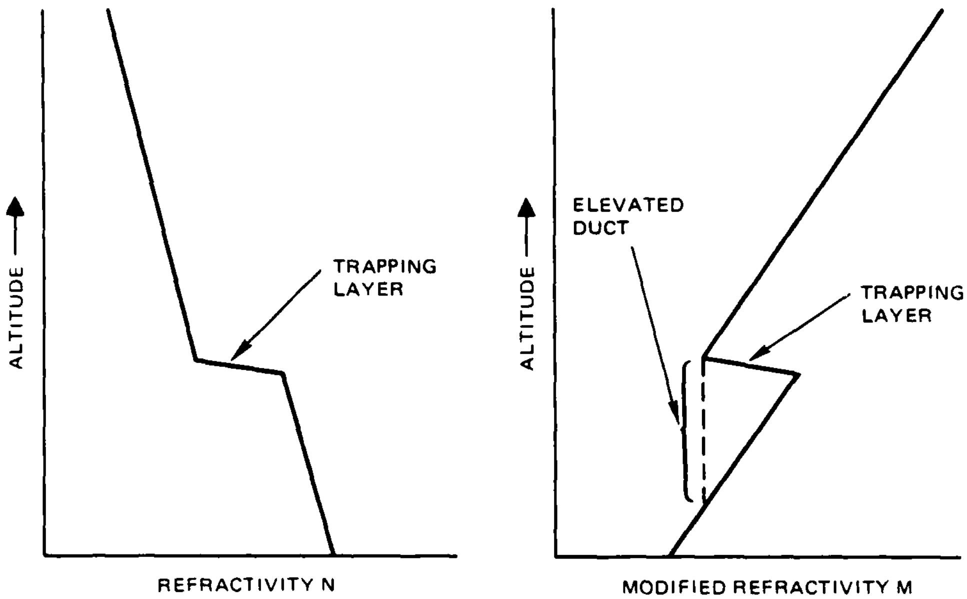


Figure 5. Refractivity N and modified refractivity M versus altitude for an elevated duct created by an elevated trapping layer.

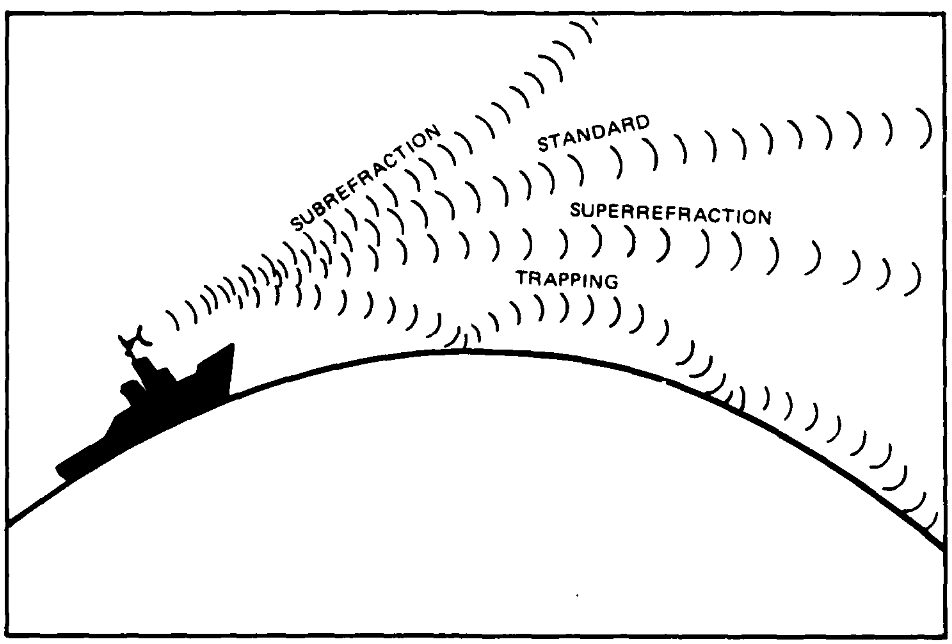


Figure 6. Relative bending for the four types of refraction.

2.1.2 Types of Ducts

There are three distinct types of ducts that are of concern to Naval EM systems and each must be treated separately. The three types are: (1) surface-based ducts from elevated refractive layers, (2) elevated ducts, and (3) evaporation ducts. Surface-based ducts from elevated refractive layers generally give extended detection, intercept, and communication ranges for all frequencies above 100 MHz, provided both the transmitter and receiver (or radar and target) are near to or within the duct. Such surface-based ducts are nearly always less than 1 km (3000 ft) thick, although thicknesses of up to 300 m (1000 ft) are more common. Elevated ducts primarily affect air-to-air surveillance, communication, EW, or weapons guidance systems. For instance, detection ranges of air targets by airborne early warning radars can be greatly extended if both the radar and target are in an elevated duct; but at the same time, radar "holes" or blind spots can occur for radars or targets above the duct. Elevated ducts occur at altitudes of near zero to 6 km (20,000 ft), although maximum altitudes of 3 km (10,000 ft) are far more common. The evaporation duct is created by the very rapid decrease of moisture at the air/sea interface and, although variable in its strength, most frequently extends ranges for surface-to-surface systems operating above 3 GHz. Each of these three types of ducts will be discussed in more detail in later sections of this document; but first, an introduction to standard (non-ducting) propagation mechanisms will be presented.

2.2 STANDARD PROPAGATION MECHANISMS

Standard propagation mechanisms are those propagation mechanisms and processes that are, in effect, independent of the existing refractivity conditions. Although standard propagation mechanisms are often described in terms of a standard refractivity profile that has a linear decrease of refractivity of about 12 N units per thousand feet, the mechanisms are generally present for all refractivity conditions even though they may be dominated by the various types of ducting.

2.2.1 Path Loss and Free Space Propagation

If an EM wave is propagating from a transmitter to a receiver (or target) and both the transmitter and receiver are sufficiently far removed from the earth or other objects, the EM wave is said to be propagating in free space. Let P_t be the power transmitted and P_r be the power received. Then the path loss (or propagation loss) between the transmitter and receiver, in decibles, is defined to be

$$L = 10\ \mathrm{Log}_{10} \frac{P_t}{P_r}\ \mathrm{dB}. \tag{3}$$

In free space, the path loss is determined by the geometrical spreading of the power over the surface of the expanding sphere centered at the transmitter and is given by

$$L_{fs} = 37.8 + 20\ \mathrm{Log}_{10}\, f + 20\ \mathrm{Log}_{10}\, R\ \mathrm{dB}; \tag{4}$$

where, f is the transmitter frequency in MHz and R is the range between the transmitter and receiver in nmi. Equation (4) assumes that both the transmitter and receiver employ lossless isotropic (radiating uniformily in all directions) antennas. L_{fs} would be a good approximation for path loss between two aircraft, if both aircraft were at reasonably high altitudes and

there were no elevated ducts present near their altitudes. However, for a transmitter or receiver near the surface, reflections from the surface must be taken into account.

2.2.2 Reflection and the Interference Region

When an EM wave strikes a nearly smooth large surface, such as the ocean, a portion of the energy is reflected from the surface and continues propagating along a path, which makes an angle with the surface equal to that of the incident ray, as illustrated by figure 7. The strength of the reflected wave is determined by the reflection coefficient which depends upon the frequency and polarization of radiation, the angle of incidence, and the roughness of the reflecting surface disturbed by the wind. Not only is the magnitude of the reflected wave reduced, but the phase of the EM wave is also altered. Typical values for the reflection coefficient for shallow incidence angles and smooth seas are .99 (i.e., the reflected wave is 99 percent as strong as the incidence wave) and 180 degrees of phase change.

As the wind speed increases, the ocean surface grows rougher and the reflection coefficient can decrease to about .15 (the phase change is unaffected). For a transmitter near the surface, the reflection process results in two paths to a receiver (or target) within line-of-sight, as illustrated by figure 8. As the geometry changes in figure 8, the relative lengths of the direct path and reflected path also change, which results in the direct and reflected wave arriving at the receiver in varying amounts of phase difference. The received signal strength is the vector sum of the signal strengths of the direct and reflected wave, which causes the received power to vary up to 6 dB above and up to 20 dB or more below the free space value.

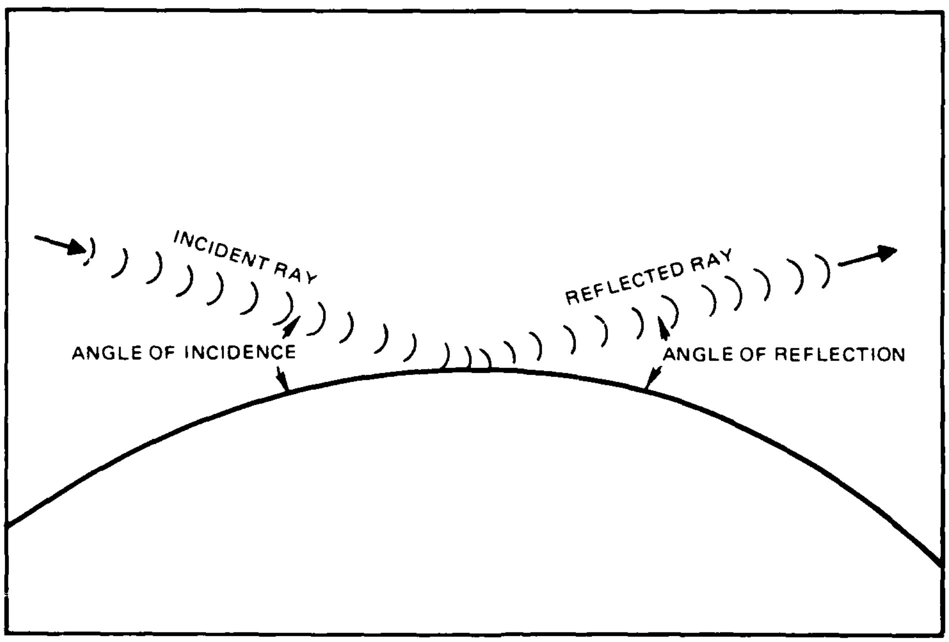


Figure 7. Incident ray and reflected ray illustrating equal angles of reflection.

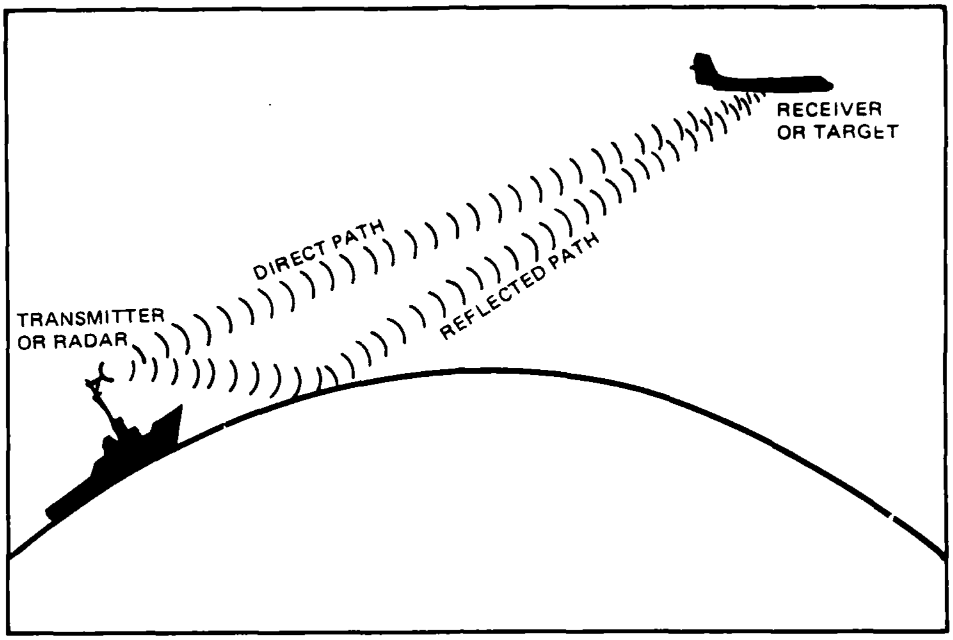


Figure 8. Surface-to-air geometry illustrating direct and sea-reflected paths.

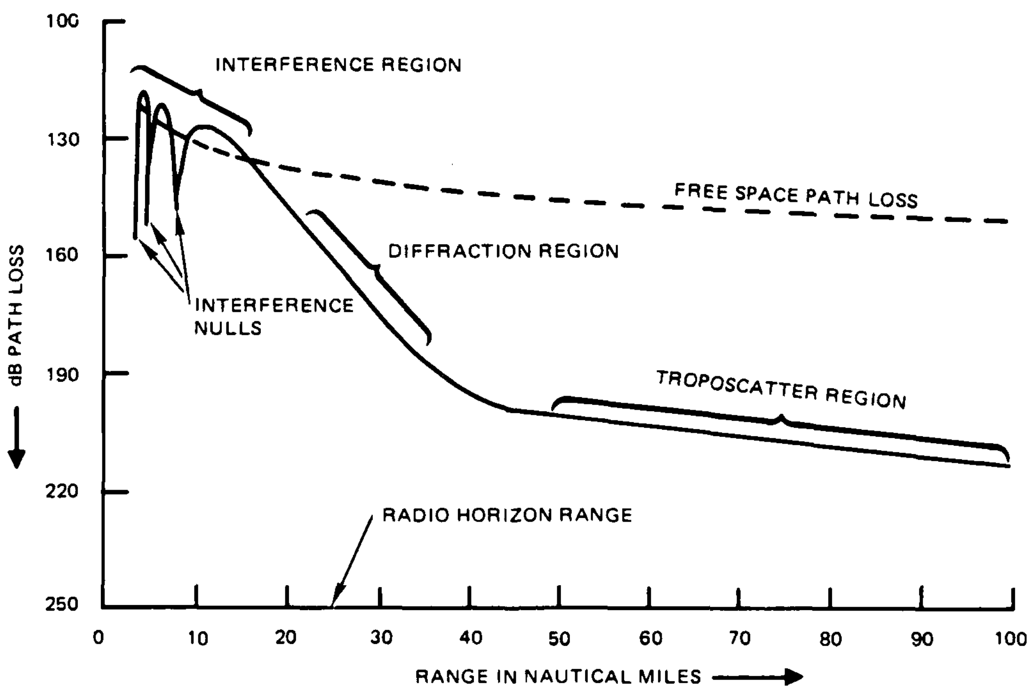


Figure 9. Path loss curve for a 5000 MHz transmitter at 60 ft and a receiver at 100 ft for a standard atmosphere.

Figure 9 shows a plot of path loss versus range for a 5000 MHz (5 GHz) transmitter located 60 ft above the sea surface and a receiver at 100 ft above the sea surface for standard refractive conditions. The region in which the path loss is dominated by the interference of the direct and sea-reflected wave is called the interference region and is labeled as such in figure 9. The free space path loss, as calculated from equation (4), is included in figure 9 for reference and illustrates how the path loss oscillates above and below the free space value in the interference region. The depth of the nulls depends very much on the surface roughness related to the wind speed. The example here, is for a smooth sea surface associated with zero wind speed, but as the wind speed increases the path loss in the nulls would approach the free space value.

2.2.3 Diffraction

Near the radio horizon range, where the path between the transmitter and receiver is just tangent to the earth's surface, the path loss is dominated by diffraction around the earth. The diffraction region, which is sometimes called the shadow region, is characterized by propagation beyond the line of sight or radio horizon because of the ability of a radio wave to travel along an interface of dissimilar materials, in this case, the earth's surface and the atmosphere. The amount of power, or signal strength, available to a receiver in this region is very dependent on the refractive conditions near the earth's surface. In fact, the various forms of ducting to be described in the following sections are actually special cases of propagation in the diffraction region. To calculate path loss in the diffraction region, in any case, is very complicated and is usually based on notions of normal-mode propagation and atmospheric waveguide considerations.

2.2.4 Tropospheric Scatter

At ranges far beyond the horizon, the path loss is dominated by a mechanism called tropospheric scatter or troposcatter (fig 9). Propagation in the troposcatter region is the result of scattering of the EM wave from refractive heterogeneities at relatively high altitudes, that are line-of-sight to both the transmitter and receiver. The calculation of path loss in the troposcatter region is quite easily performed using semi-empirical formulations. The rate at which the path loss increases with range, within the troposcatter region, is considerably less than the rate in the diffraction region (fig 9). However, the path loss values found in this region are so high that it is impossible for any known radar system to detect targets. Troposcatter is an important consideration for certain communications systems and ESM receivers.

2.2.5 Absorption

A standard propagation mechanism that was not illustrated in figure 9, but should be mentioned, is absorption. Oxygen and water vapor molecules in the atmosphere absorb some energy from radio waves and convert it to heat. The amount of absorption is highly dependent on the radio frequency and is negligible, compared to all the other propagation considerations, below 20 GHz. Also, absorption by rain drops and other forms of precipitation can be important at some frequencies, but this type of absorption is very hard to model and even harder to acquire environmental data on. For these reasons, absorption effects are ignored in the IREPS programs.

2.2.6 Maximum Range Calculation

Path loss curves, such as the example shown in figure 9, can be very useful in determining the maximum range capability for a particular EM system. If the maximum path loss threshold (to just detect, communicate, or intercept) is known, then the maximum range for that system will be: the range beyond which the path loss is always greater than the threshold. For example, if a 5000 MHz radar has a one-way path loss detection threshold of 160 dB, for a 90 percent probability of detection of a 1 m^2 target for a given false alarm rate, then figure 9 would indicate a maximum detection range of 25 nmi if the radar were at 60 ft and the target at 100 ft. The one-way path loss threshold can always be calculated from equation (4) if the maximum free space range is known for the particular system. Again, for the case of the example, if the system is known to have a maximum free space range of 100 nmi, then equation (4) results in a path loss threshold of 151.8 dB and figure 9 would imply a maximum range (for standard atmospheric conditions) of 21 nmi.

Sometimes, a more convenient form to display the performance capability of an EM system is the vertical coverage diagram, which shows those areas on a height-versus-range plot, where the path loss values are always less than the path loss threshold just described. Figure 10 is an example of such a coverage diagram for a standard atmosphere for the 220 MHz SPS-28 air-search radar, operating at 80 ft above the sea surface and based on a free space detection range of 100 nmi. The shaded area in the diagram represents the area in which the path loss is less than the threshold for detection and, therefore, represents the area where the radar would be expected to detect air targets. The display clearly shows the effects of the interference region with the lobes that extend out to 200 nmi and the deep interference nulls that

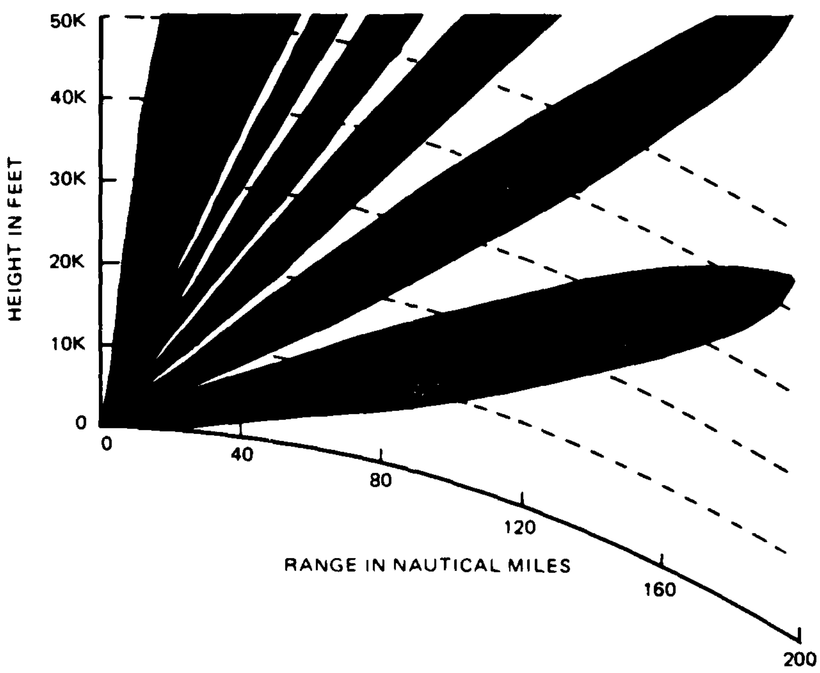


Figure 10. Coverage diagram for the 220 MHz SPS-28 air-search radar at 80 ft for a standard atmosphere and based on a free-space detection range of 100 nmi.

reduce the detection range to within 40 nmi. The lower edge of the bottom lobe, determined by calculations in the diffraction region, is the maximum range for each altitude. The curved-earth display is usually used in the coverage diagrams, because it has been found easy to understand and it simplifies some of the computer routines used to generate the coverage diagrams.

2.3 SURFACE-BASED DUCTS FROM ELEVATED REFRACTIVE LAYERS

Over ocean areas, there often exists a cool moist marine air mass extending vertically, from the ocean surface, to an altitude of up to a few hundred metres. The air mass well above this altitude can be much warmer and drier than the marine air, for a variety of reasons, and it creates a transition region in which the air warms up and dries out rapidly with increasing altitude. The warming and drying of the air causes the modified refractivity to decrease with height, thus forming a trapping layer as illustrated in figure 11. As discussed earlier, if the M-value at the top of the trapping layer is less than the M-value at the ocean surface, a surface-based duct will be formed. To some extent, this kind of duct will trap EM signals at <u>all</u> frequencies of concern, independent of the height of the trapping layer, and will generally give extended radar detection range of surface targets, as illustrated in figure 12.

In addition, surface-based air-search radars can be dramatically affected by surface-based ducts for detection of air targets flying within the duct. Figure 13 shows a coverage diagram for the SPS-28 radar with the same parameters as in figure 10, but in the presence of a 1000 ft high surface-based duct. Note that the detection of air targets flying within the first 1000 ft can be detected at ranges up to 115 nmi which is about 3 times as far as they could have been detected in a standard atmosphere. The amount of range enhancement within the duct is dependent on the radar frequency, with higher frequency radars giving greater detection ranges. Since the SPS-28 uses the lowest Navy radar frequency band, figure 13 represents the minimum enhancement that might be expected in a surface-based duct. Note also, that the lowest interference lobes have been refracted downward, compared to the corresponding lobes shown for a standard atmosphere in figure 10. Such downward refraction is typical in the presence of surface-based ducts.

Surface-based ducts also greatly affect communications and EW systems, with the maximum effects occurring when both the transmitter and receiver are within the duct. Shipboard ESM receivers can particularly benefit from this type of duct, which can result in intercept ranges dramatically greater than those under standard atmospheric conditions. Also, ship-to-ship uhf communications (or ship-to-air for low flying aircraft) can be enhanced to many times the normal communications range.

The rate of occurrence of surface-based ducts created by elevated refractive layers depends on geographic location, season, and time of day. They are usually rare at the extreme northern or southern latitudes (occurring perhaps 1 percent of the time, or less), but can occur up to as much as 20 to 40 percent of the time in some important operational areas such as the southern California off-shore area, the eastern Mediterranean, or the northern Indian Ocean. Also, surface-based ducts tend to occur more often during the warmer months and during daylight hours. On a day-to-day basis surface-based ducts can only be detected by making some measurement of the refractivity of the lower atmosphere at least up to 1 km (3000 ft). These measurements are normally made either using a radiosonde or microwave refractometer. Both of these measurements will be described in section 2.7.1.

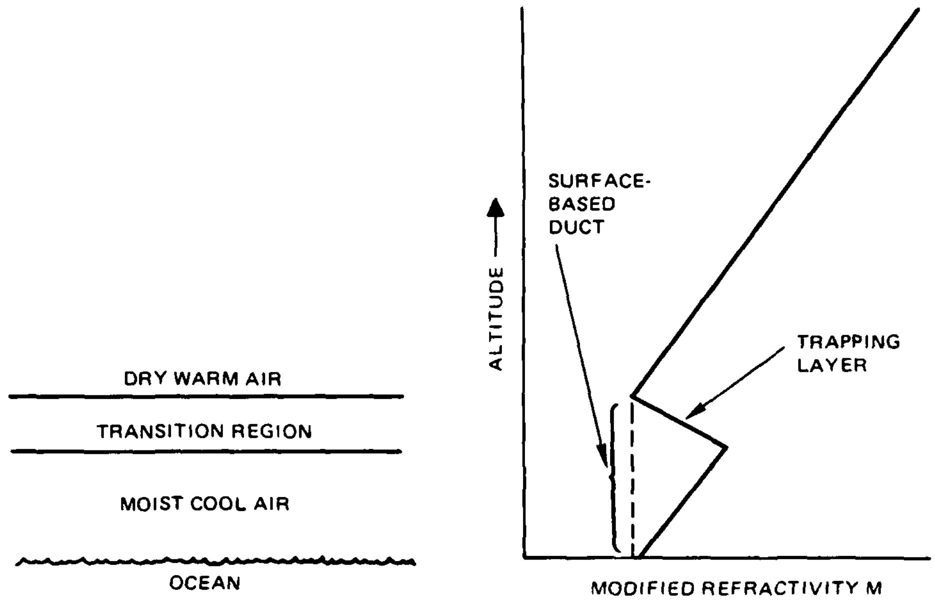


Figure 11. Air masses and transition region responsible for the trapping layer and resulting surface-based duct shown on the right.

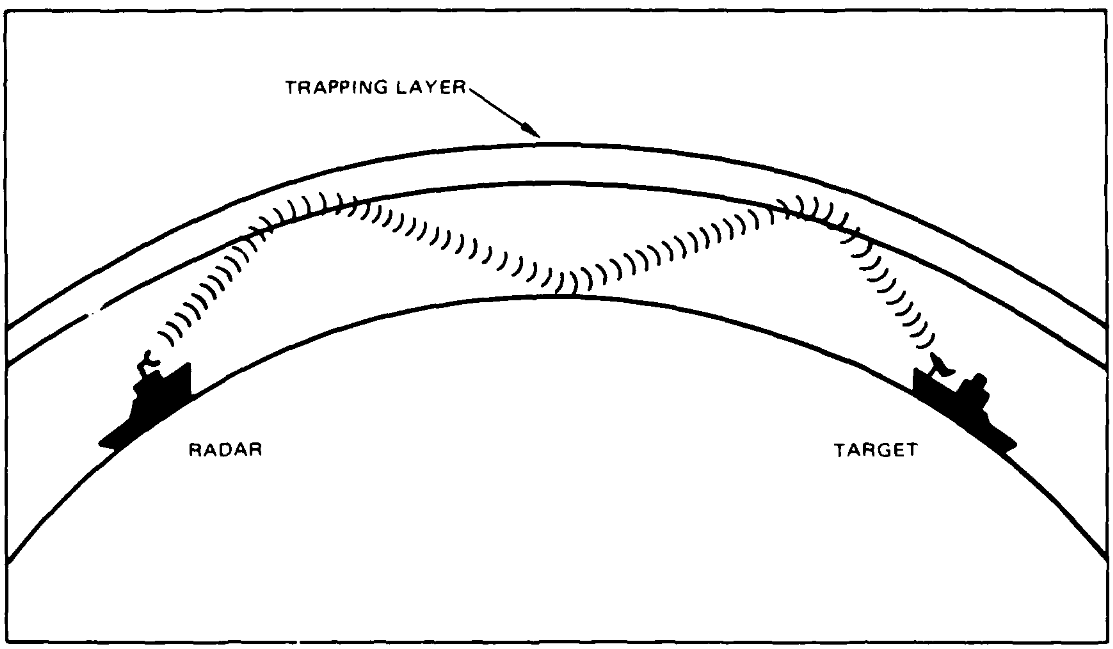


Figure 12. Radar wave path for a surface-based duct created by an elevated trapping layer.

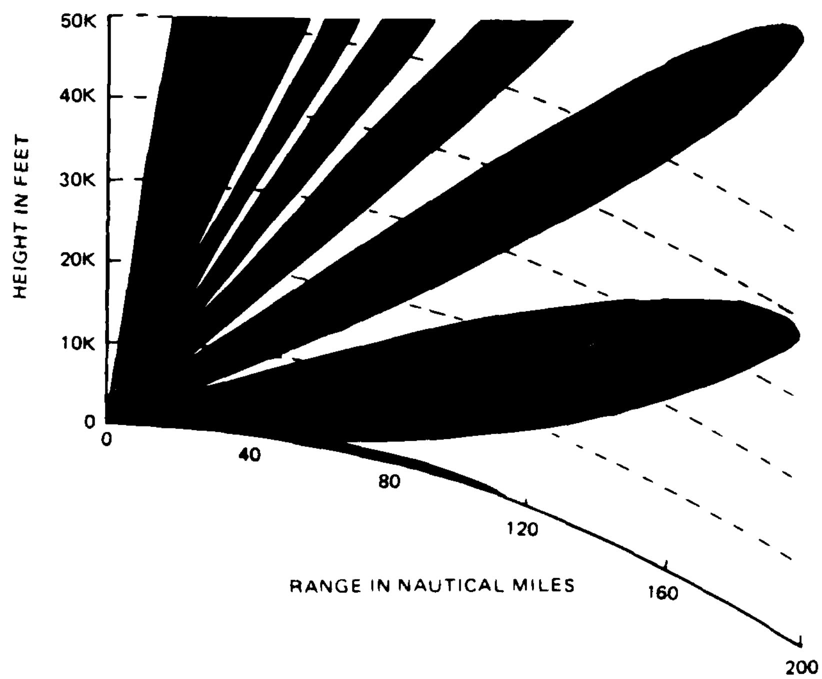


Figure 13. Coverage diagram for the 220 MHz SPS-28 air-search radar at 80 ft for a 1000 ft high surface-based duct and based on a free-space detection range of 100 nmi.

2.4 ELEVATED DUCTS

When the transition region described in the previous section occurs at a higher altitude, than necessary to produce a surface-based duct, then an elevat d duct is formed. The N and M unit profiles typical of an elevated duct were previously discussed and illustrated in figure 5. It should be noted that the meteorological process responsible for both surface-based and elevated ducts is identical; namely, the transition between two differing air masses creates a trapping layer. In fact, a surface-based duct can become an elevated duct, and vice-versa, by relatively small changes in the strength or vertical location of the trapping layer.

Although very low elevated ducts can give enhanced performance ranges to surface-based EM systems, the most dramatic effects caused by elevated ducts are for airborne EM systems. An airborne early-warning radar, for example, can utilize elevated ducts to increase its detection range for targets located within the elevated duct if the radar is also in the duct. Figures 14 to 16 illustrate the effect of a strong elevated duct on a typical airborne radar, with a 150 nmi free space detection range, for three radar altitudes. The elevated duct occurs between 15 000 and 17 000 ft and figure 14 shows the enhanced range capability within the duct if the radar is located at 16 000 ft. Notice, however, the large gap in coverage beginning at about 40 nmi and extending outwards above the elevated duct. This gap is often referred to as a "radar hole" and is caused by the trapping of that portion of the wave front within the duct that would normally be in the gap. Actually, the term "radar hole" is not a very good description of the effect because it is possible to detect targets in certain cases within

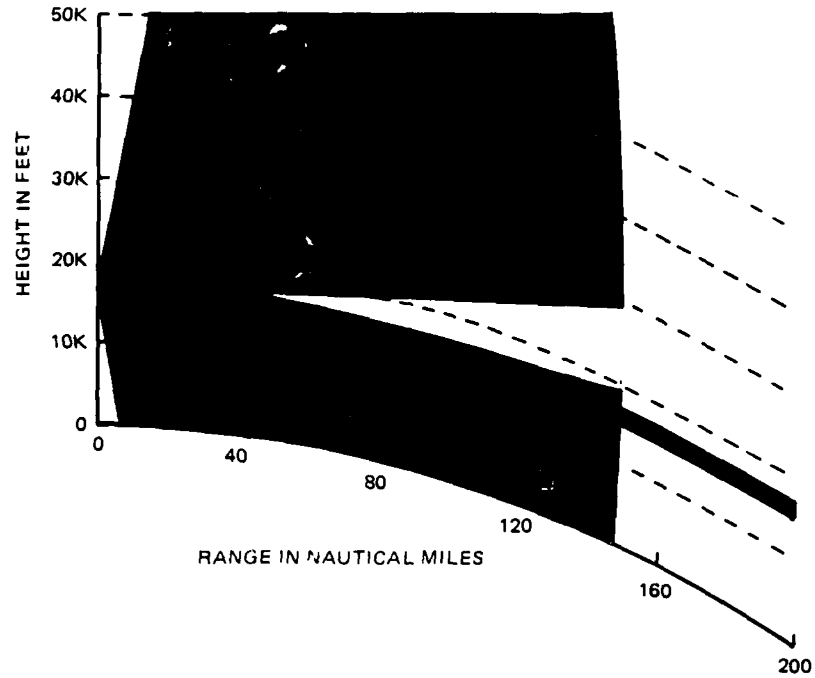


Figure 14. Coverage diagram for typical airborne early-warning radar with 150 nmi free space detection range in the presence of a 15 to 17 kft elevated duct. Radar altitude is 16 kft.

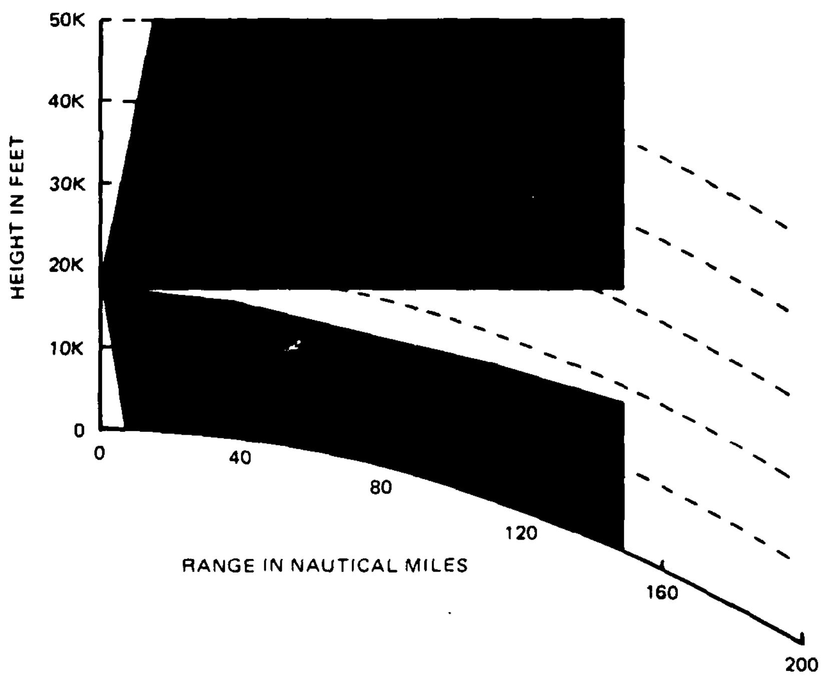


Figure 15. Coverage diagram for typical airborne early-warning radar with 150 nmi free space detection range in the presence of a 15 to 17 kft elevated duct. Radar altitude is 17 kft.

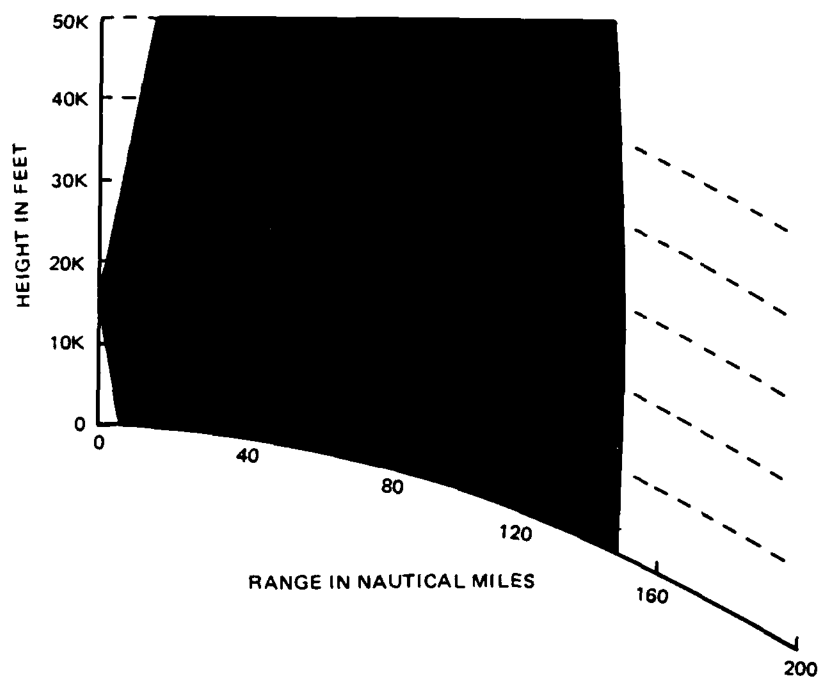


Figure 16. Coverage diagram for typical airborne early-warning radar with 150 nmi free space detection range in the presence of a 15 to 17 kft elevated duct. Radar altitude is 15 kft.

this region, due to energy that escapes or leaks out of the duct or propagates to this region via other paths or mechanisms. Generally, however, the detection of air targets in the gap region is significantly reduced and the term "radar hole" has become widely accepted.

Figure 15 shows the effect of moving the radar up to the very top of the duct to 17 000 ft which results in no enhanced detection capability within the duct, but still creates a large hole in the coverage diagram. If the radar were to be placed at even higher altitudes, then the radar hole would begin at increasing ranges and become smaller until, finally, the hole would begin at a range exceeding the normal maximum detection range and would become inconsequential. In fact, figure 15 shows the worst altitude to place the radar, since the largest hole will result.

Figure 16 shows the effect of placing the radar at the very bottom of the duct, at 15 000 ft, which results in no hole at all. Any radar altitude below an elevated duct will never result in a radar hole and can therefore be the optimum location to minimize the radar hole problem. However, if the elevated duct is low enough, then being below it can cause a reduced horizon problem that can affect overall radar coverage. In the example, the radar is still high enough so that the radar horizon is in excess of the maximum range of the radar, so there is no reduced coverage.

Elevated ducts can affect air-to-air communications and ESM intercept ranges in much the same way as the radar cases described above. The effects are somewhat frequency dependent for all EM systems, with the higher frequencies being the most likely to follow the effects

illustrated by the radar examples. Lower frequencies may not be trapped sufficiently to cause all the effects illustrated.

To properly assess the effects of elevated ducts, a measurement of the refractivity of the atmosphere is needed which is usually accomplished with a radiosonde or microwave refractometer. See section 2.7.1.

2.5 EVAPORATION DUCTS

A very persistent ducting mechanism is created over ocean areas by the rapid decrease of moisture immediately above the ocean surface. For continuity reasons, the air adjacent to the ocean is saturated with water vapor and the relative humidity is thus 100 percent. This high relative humidity decreases rapidly in the first few metres to an ambient value which depends on varying meteorological conditions. The rapid decrease of humidity initially causes the modified refractivity M to decrease with height; but at greater heights, the humidity distribution will cause M to reach a minimum and thereafter increase with height, as illustrated in figure 17.

The height at which M reaches a minimum value is called the evaporation duct height and is a measure of the *strength* of the evaporation duct. The evaporation duct, which extends from the surface up to the duct height, is much thinner and weaker than the surface-based ducts described earlier. As a result, the effect that the evaporation duct will have on EM systems is very dependent on the particular frequency and, to a lesser extent, on the height of the antenna above water. Generally, the evaporation duct will only affect surface-to-surface EM systems, although some effects can occur for relatively low flying aircraft. It must be emphasized that the evaporation duct height is only a measure of the *strength* of the duct and is not a height below which an antenna must be located to give extended ranges. For a given surface-search radar, detection range will generally increase as the duct increases and, for sufficiently large duct heights, surface targets will be detected at ranges significantly beyond the horizon, as illustrated in figure 18. The frequency of occurrence of duct heights sufficiently large to give beyond-the-horizon detection capability to a particular radar varies significantly according to geographic location, season, and time of day. Generally, duct heights will be greater at latitudes nearer the equator, during the summer season, and during daylight hours. For example, duct heights large enough to extend the detection range of the most common surface-search radar, the SPS-10, occur 82 percent of the time in the eastern Mediterranean during summer days, but only 1 percent of the time in the Norwegian Sea during winter nights.

To illustrate these concepts, figure 19 shows the relationship between maximum detection range and evaporation duct height for the SPS-10 surface-search radar. The radar antenna in this case is at 39 metres above the sea surface and a 35 000 square-metre radar cross-section target 10 metres above sea level was assumed, corresponding to a naval warship of destroyer size. The maximum detection range has been calculated, based on a 90 percent probability of detection, a 1×10^{-8} false alarm rate, a steady target, and 5 dB of system loss. Figure 19 shows a detection range of 22 nmi (corresponding closely to the normal radar horizon) for a duct height of zero and increasing detection range for increasing duct heights.

Generally, the evaporation duct is only strong enough to affect EM systems operating above about 3 GHz, although systems with frequencies down to about 1 GHz can benefit

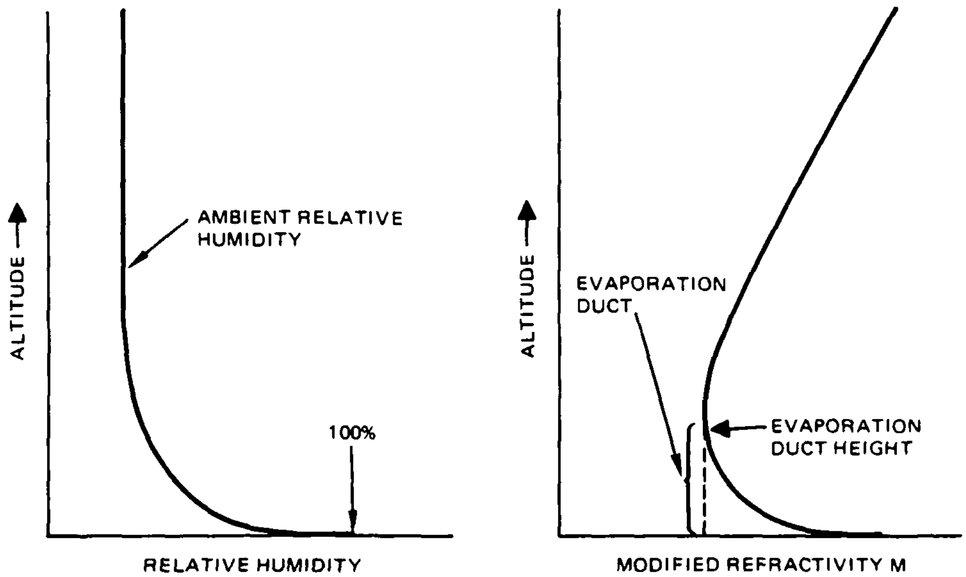


Figure 17. Relative humidity and modified refractivity M versus altitude for an evaporation duct.

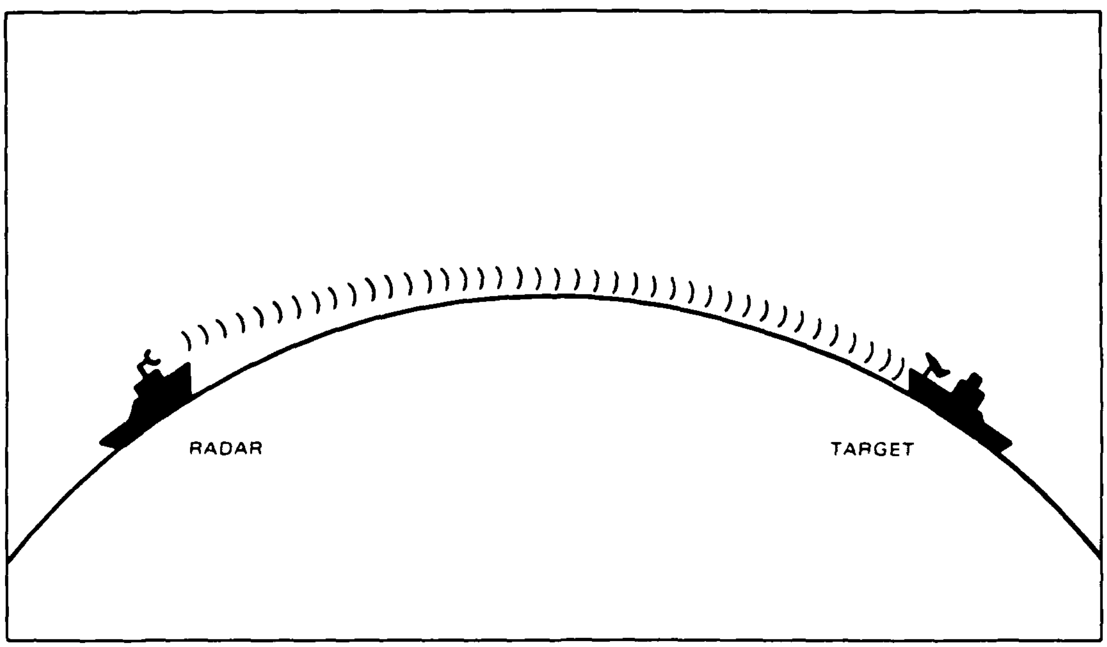


Figure 18. Radar wave path under evaporation ducting conditions resulting in beyond-the-horizon detection.

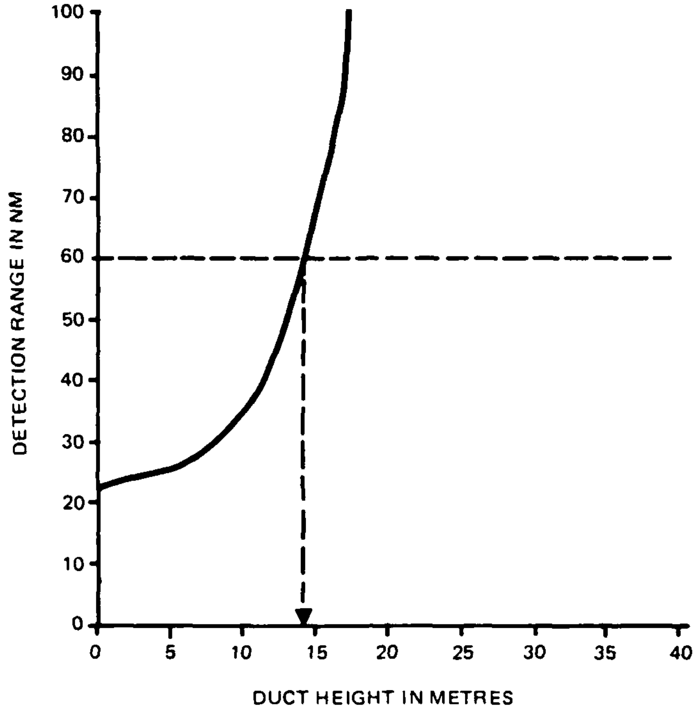


Figure 19. Detection range versus evaporation duct height for the SPS-10 for an antenna height of 39 metres and 90% probability of detection of a destroyer-sized surface target.

from the mechanism on occasion. ESM intercept ranges for surface-to-surface paths can be greatly extended by the evaporation duct and certain communications systems, such as the Multi-Channel Jezebel Relay, could also experience enhanced ranges when both terminals are near the ocean surface. Ship-to-ship uhf communications frequencies are too low to benefit from the evaporation duct, but uhf ranges can be extended by surface-based ducts as explained in section 2.3.

The proper assessment of the evaporation duct can only be performed by making surface meteorological measurements and inferring the duct height from the known meteorological processes occurring at the air/sea interface, as will be briefly described in section 2.7.2. The evaporation duct height *cannot* be measured using a radiosonde or microwave refractometer.

2.6 SEA CLUTTER AND DUCTING

Under certain circumstances, a radar's performance is limited by radar returns from the sea surface known as sea clutter. If the sea clutter return is stronger than a target at the same range, then it will be difficult or impossible to detect the target. Many radars use a Moving Target Indicator (MTI) to enhance the radar's ability to detect fast moving air targets in the presence of sea clutter, by using sophisticated signal processing techniques that depend on the doppler shift of the radar frequency associated with moving targets. MTI is usually sufficient to overcome the sea clutter problem in normal circumstances, but in the presence

of surface-based or evaporation ducts the sea clutter return can be greatly enhanced and overcome the MTI ability to detect the moving target. In addition, the horizontal extent of sea clutter can be greatly extended during ducting conditions and mask targets over much greater ranges than normal.

Figure 20 illustrates how a surface-based duct created by an elevated layer can result in sea-clutter return from a significant range, that can mask air targets at the same range. The strength of the sea-clutter return is very dependent on the strength of the duct and on the roughness of the sea surface which is controlled primarily by the surface wind speed and direction. A surface-based duct, such as that illustrated in figure 20, usually results in several discrete range intervals of high sea clutter because of the typical propagation path in a surface-based duct (fig 12). These discrete intervals are normally independent of azimuth angle, which can give the appearance of sea-clutter rings centered at the radar when viewed on a PPI display. Evaporation ducts, on the other hand, will result in continuous, enhanced sea-clutter return with range.

Airborne radars are also affected by sea clutter and can have their performance severely impaired by enhanced clutter from ducting conditions, particularly for surface-search applications. Often, nearby land clutter, as well as sea clutter, can be significantly enhanced which can cause target masking and general confusion to the radar operator.

The amount of sea-clutter return is very difficult to calculate for ducting conditions and no known algorithms yet exist for programs such as IREPS to take this mechanism into account for radar coverage displays.

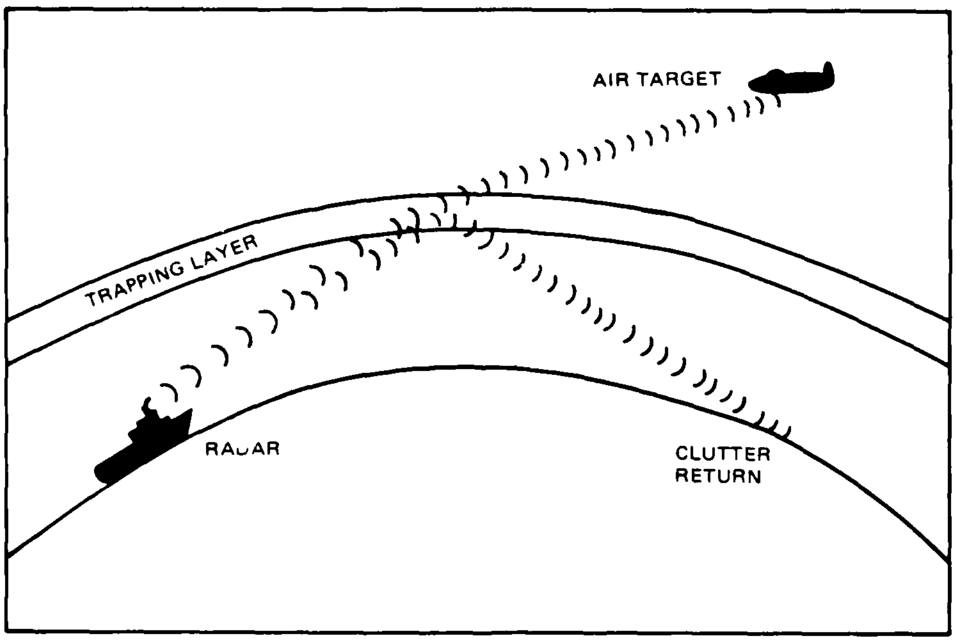


Figure 20. Air-search radar geometry showing possible clutter return from rough sea surface at same range as air target for a surface-based duct.

2.7 METEOROLOGICAL MEASUREMENTS TO ASSESS REFRACTIVE EFFECTS

This section describes measurements that can be taken in-situ to assess refractive effects as they change with the changing environment.

2.7.1 Surface-based and Elevated Ducts

To determine the presence of either a surface-based duct or an elevated duct, measurements of the vertical distribution of the refractivity or of the air temperature and humidity must be made. There are two primary methods by which such measurements are made: namely, the microwave refractometer and the radiosonde.

The AMH-3 refractometer is a device, designed for installation aboard the E-2 aircraft, which directly measures refractivity and records it on a magnetic cassette tape for post-flight processing. The processing includes calculations of modified refractivity M which is plotted as a function of altitude, so that the presence and vertical extent of ducts can be determined as previously discussed. However, at the present time the AMH-3 is not operational in the Navy and refractivity information must be calculated from radiosonde measurements.

The radiosonde is a balloon-borne expendable package that measures temperature, humidity, and pressure as the package ascends through the atmosphere. The measurements are sent via a small radio transmitter to a receiver at the surface and recorded on a moving paper chart. All CVs, LPHs, LHAs and any surface ship with a mobile meteorological team embarked are equipped to operate the equipment and translate the results into refractivity as functions of height. The IREPS program can use inputs, either from the refractometer or the radiosonde, in assessing refractive effects. This will be explained in section 3.4.

2.7.2 Evaporation Ducts

To determine the evaporation duct height at any given time and place, a method has been devised that requires measurements of sea temperature; and at a convenient height above the sea surface, air temperature, humidity, and wind speed. This method is based on the known variation of temperature and humidity near the air/sea interface. It should be noted that the evaporation duct height cannot be determined from normal radiosonde or refractometer data, but must be determined by the method presented in this section. The four required measurements are:

TS: Sea Temperature in degrees Celsius,

TA: Air Temperature in degrees Celsius,

RH: Relative Humidity in percent, and

WS: True Wind Speed in knots.

TS is a measurement of the sea temperature, at the surface, and is best measured with an accurate thermometer and a small bucket which has been lowered into water undisturbed by the ship's wake. Injection water temperature measurements by themselves are generally very inaccurate for the purposes required here and should be avoided if at all possible. It is recognized that obtaining a good sea surface temperature measurement, while underway at reasonable ship speeds, can be very difficult. For ships so equipped, satisfactory measurements

should be attainable through the use of expendable bathythermographs (XBTs). Other equipments that could be used, but which are not normally in ship's allowance, are specially designed "bucket thermometers."

A single measurement of TA and RH is required at any convenient height aboard ship above 6 metres (20 ft) but must be made in a way to minimize any ship-induced effects such as heating. *These measurements are best performed with a hand-held psychrometer* (such as the ML-450A/UM), pointing the instrument into the wind from the most windward side of the ship.

For the measurement of WS, the ship's anemometer corrected for the ship's course and speed is sufficient. With these required inputs, IREPS can accurately calculate the evaporation duct height and then use the duct height in calculating its effects on the various EM systems.

3.0 OPERATION

3.1 THE IREPS PRODUCTS

After the proper environmental data has been entered into IREPS, as will be explained in detail in section 3.4, there are four basic products that can be requested from IREPS. These four products are:

(1) a propagation conditions summary

(2) a printout (alphanumeric listing) of the environmental data

(3) a coverage diagram

(4) a path loss diagram.

Each product is produced on an 8-1/2 by 11 inch printout consisting of a mixture of alphanumeric labels and graphics displays. There are a number of other displays that IREPS generates on the CRT that are intended to help the operator enter data, select products, and otherwise run the program; but, these cannot be printed out and are not considered IREPS products.

3.1.1 The Propagation Conditions Summary

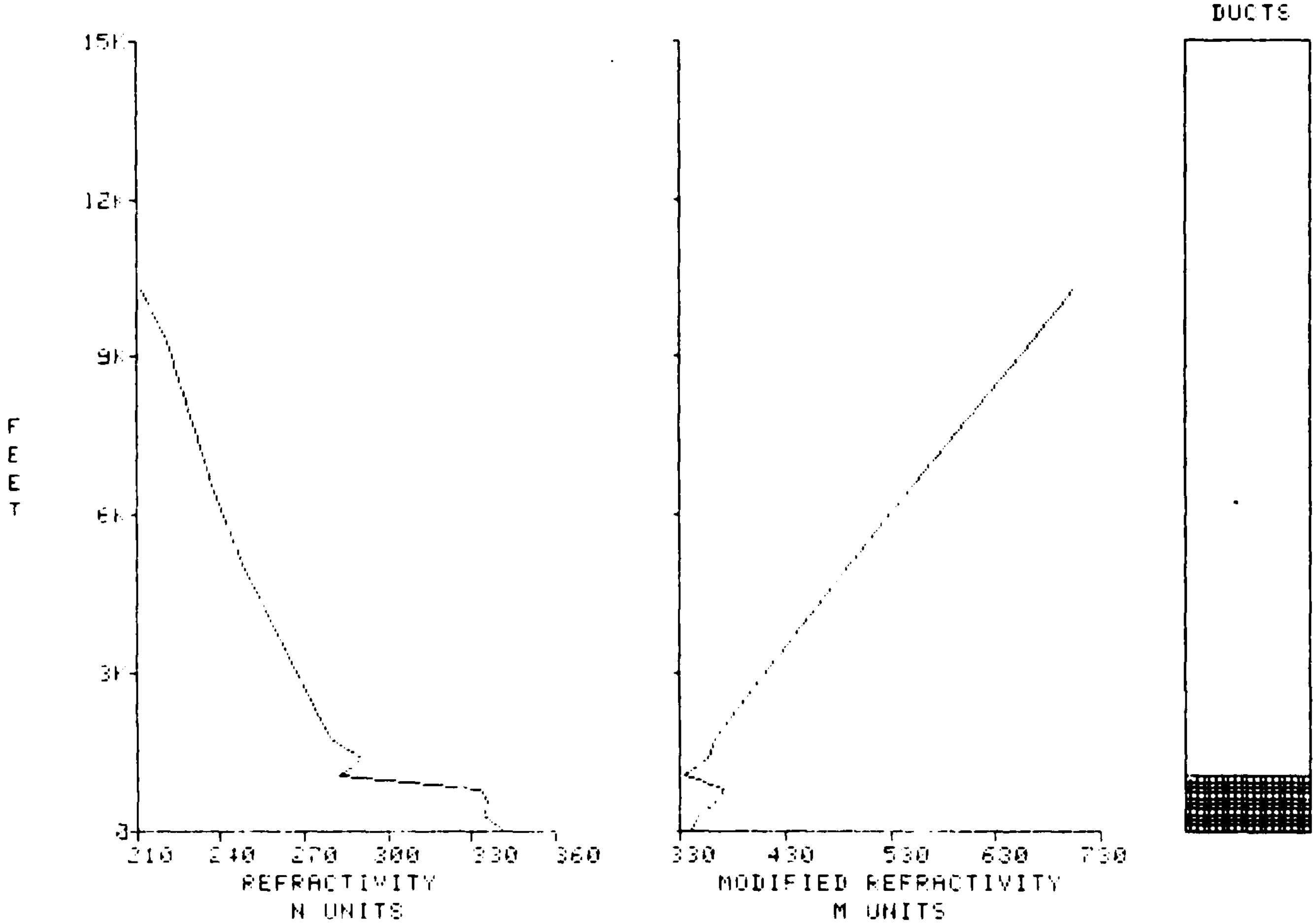
Figure 21 shows an example of the propagation conditions summary. This product is used to show the existing refractive conditions for the location and date/time of the environmental data set and to give a plain language narrative assessment of what effects may be expected on an EM system-independent basis. The summary shows a refractivity in N-units and a modified refractivity in M-units plot versus altitude. The presence and vertical extent of any ducts are shown by shaded areas on the vertical bar at the right hand side of the product. In this case there is a surface-based duct created by an elevated layer extending up to about 1100 ft. The wind speed and evaporation duct height are listed numerically on this product. Near the bottom of the product are three categories labeled SURFACE-TO-SURFACE, SURFACE-TO-AIR, and AIR-TO-AIR in which occur brief statements concerning the general performance of EM systems in each geometry category. The statements are system independent assessments and are true only in a general sense. For specific systems, one of the other products must be generated in order to obtain a proper assessment of its performance. The bottom line of the summary lists the surface refractivity and the setting for the SPS-48 height-finder radar to properly account for refractive effects in its calculations of elevation angle and height.

3.1.2 The Environmental Data List

Figure 22 is an example of the environmental data list product that is used primarily for checking numeric values of data entries that provide numeric values of dew point depression, altitude, N units, N unit gradient, M units, and a description of the refractive condition. Also, this product can be used to archive environmental data sets for future use, since all required input values are listed numerically. In addition, the last line of this product is the same as that of the summary which displays surface refractivity and the proper setting for the SPS-48.

**** PROPAGATION CONDITIONS SUMMARY ****

LOCATION: 31 56N 118 36W
DATE/TIME: 17 JUN 0045Z



WIND SPEED 12.0 KNOTS

EVAPORATION DUCT HEIGHT 28.0 FEET
EVAPORATION DUCT HEIGHT 8.5 METRES

SURFACE-TO-SURFACE
EXTENDED RANGES AT ALL FREQUENCIES

SURFACE-TO-AIR
EXTENDED RANGES FOR ALTITUDES UP TO 1,072 FEET
POSSIBLE HOLES FOR ALTITUDES ABOVE 1,072 FEET

AIR-TO-AIR
EXTENDED RANGES FOR ALTITUDES UP TO 1,072 FEET
POSSIBLE HOLES FOR ALTITUDES ABOVE 1,072 FEET

SURFACE REFRACTIVITY: 341 ---SET SPS-48 TO 344

Figure 21. Propagation conditions summary product.

**** ENVIRONMENTAL DATA LIST ****

LOCATION: 31 56N 118 36W
DATE/TIME: 17 JUN 0045Z

WIND SPEED 12.0 KNOTS

EVAPORATION DUCT PARAMETERS:
SEA TEMPERATURE 18.2 DEGREES C
AIR TEMPERATURE 15.1 DEGREES C
RELATIVE HUMIDITY 89 PERCENT
EVAPORATION DUCT HEIGHT 28.0 FEET
EVAPORATION DUCT HEIGHT 8.5 METRES

SURFACE PRESSURE = 1008.0 mB
RADIOSONDE LAUNCH HEIGHT = 60.0 FEET

LEVEL	PRESS (mB)	TEMP (C)	RH (%)	DEW PT DEF(C)	FEET	N UNITS	N/Kft	M UNITS	CONDITION
0	------	----	----	----	0.0	340.7	-12.0	340.7	NORMAL
1	1,008.0	15.1	89.0	1.8	60.0	340.0	-28.2	342.9	SUPER
2	1,000.0	14.2	87.0	2.1	281.6	333.8	15.6	347.2	SUB
3	993.0	13.9	95.0	.8	476.6	336.8	-10.9	359.6	NORMAL
4	982.0	13.3	97.0	.5	785.3	333.4	-176.4	371.0	TRAP
5	972.0	20.4	25.0	20.8	1,071.8	282.9	27.2	334.2	SUB
6	962.0	21.5	34.0	16.6	1,364.9	290.9	-28.9	356.2	SUPER
7	949.0	21.5	27.0	19.9	1,751.3	279.7	-9.4	363.5	NORMAL
8	862.0	20.6	25.0	20.8	4,477.3	254.0	-9.5	468.2	NORMAL
9	850.0	19.7	25.0	20.7	4,873.5	250.2	-7.6	483.4	NORMAL
10	807.0	20.0	25.0	20.7	6,339.1	239.0	-6.0	542.3	NORMAL
11	726.0	14.5	34.0	15.8	9,299.4	221.2	-8.9	666.1	NORMAL
12	700.0	11.8	34.0	15.5	10,305.6	212.2	------	705.3	------

SURFACE REFRACTIVITY: 341 ---SET SPS-48 TO 344

Figure 22. Environmental data list product.

3.1.3 The Coverage Display

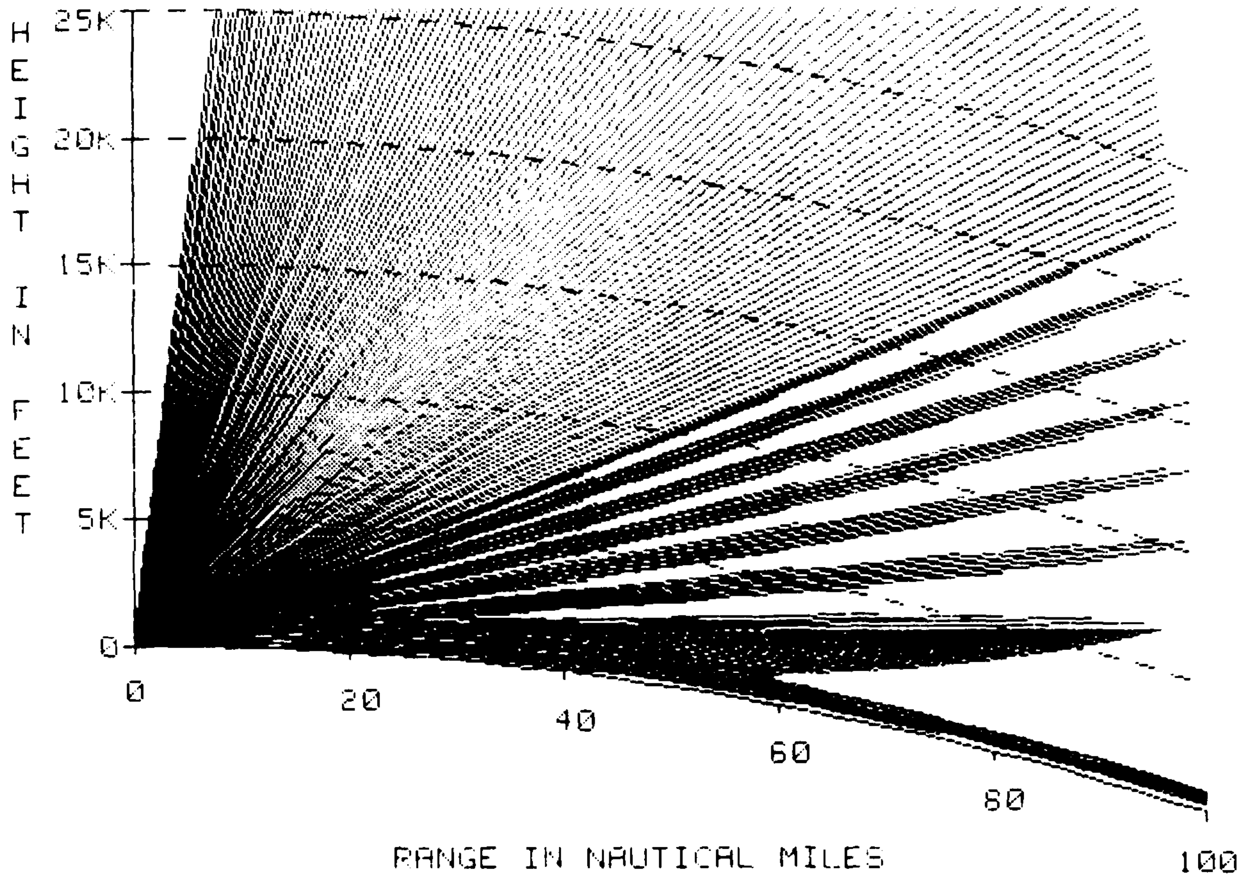
Figure 23 is an example of an IREPS coverage display product that shows the area of coverage on a curved-earth range-versus-height plot. The shaded area in the plot corresponds to the area of detection or communication which, in this example, is based on a 50 nmi free space detection range for a 1300 MHz SPS-12 air-search radar operating at 100 ft above the sea surface. In other words, if this radar could detect a certain target at 50 nmi in free space, then it will actually detect the same target anywhere within the shaded area. In addition to the basic coverage display plot, this product also includes the location and date/time labels for the refractivity conditions upon which it is based and labels to describe the type of system and detection definition, plus a numeric listing of the free space range, the frequency, and the transmitter or radar antenna height.

The coverage display has a number of uses in assessing both radar and communications coverage. It is useful to many squadrons in planning flight profiles and to CIC or TSC shipboard personnel in planning and controlling airborne platform locations. A more complete list of tactical uses of this product will be presented in section 3.3.

**** COVERAGE DISPLAY ****

SPS-12

LOCATION: 31 56N 118 36W
DATE/TIME: 17 JUN 0045Z



AIR-SEARCH RADAR
BASED ON 50 NM FREE SPACE DETECTION RANGE FOR ARBITRARY TARGET

SHADED AREA INDICATES AREA OF DETECTION OR COMMUNICATION

FREE SPACE RANGE: 50 NAUTICAL MILES
FREQUENCY: 1300 MHZ
TRANSMITTER OR RADAR ANTENNA HEIGHT: 100 FEET

Figure 23. Coverage display product.

3.1.4 The-Path-Loss Display

Figure 24 is an example of path loss display product that shows one-way path loss in dB versus range. The dashed line in the display represents the threshold for detection, communication, or intercept. In the example, it is based on a 50 percent probability for detection of a destroyer-sized surface target, with a false alarm rate of 1×10^{-8} for the 5600 MHz SPS-10 surface-search radar. In the example, the radar is located at 160 ft and the target is located at 50 ft above the ocean surface. The display shows path loss to be less than the threshold, out to 100 nmi in the example; hence, detection would be expected at all ranges up to 100 nmi. The example is for the refractive conditions of figure 21 which are characterized by a strong surface-based duct. If there were no duct, then the path loss in figure 24 would have crossed the detection threshold at about 25 nmi. In addition to the basic path loss plot, this product also includes the labels for location and date/time for the applicable refractivity conditions, labels to describe the system and definition of detection, numeric values for the free space range, frequency, transmitter/radar height, and receiver/target height. The path loss at the dashed line threshold is the one-way free space path loss from equation (4) based on the free space range listed.

The path loss display is very useful in assessing surface-search radar ranges, communication ranges, ESM intercept ranges, and many other applications when both the transmitter and receiver (or radar and target) heights can be specified. A more complete discussion of tactical uses of the loss display will be presented in section 3.3.

3.2 LIMITATIONS OF THE IREPS MODELS

There are a number of limitations in the IREPS models and resulting displays that the user needs to be aware of. The IREPS models and software are constantly undergoing revisions and many of the limitations discussed here will be overcome in the near future.

3.2.1 Frequency

The frequency range for which the models have been developed is from 100 MHz to 20 GHz. Any use of the IREPS program for frequencies outside these bounds is improper and erroneous assessments are likely to result. The models specifically do not apply to any hf system.

3.2.2 Clutter

The models do not include any effects produced by sea or land clutter in the calculation of radar detection ranges. This shortcoming may be of importance for air-search radars in the detection of targets flying above surface-based or strong evaporation ducts, but it is not expected to significantly affect the predicted enhanced detection ranges within a duct. Specifically, for surface-based ducts, the actual detection capability at some ranges may be reduced for air targets flying above the duct.

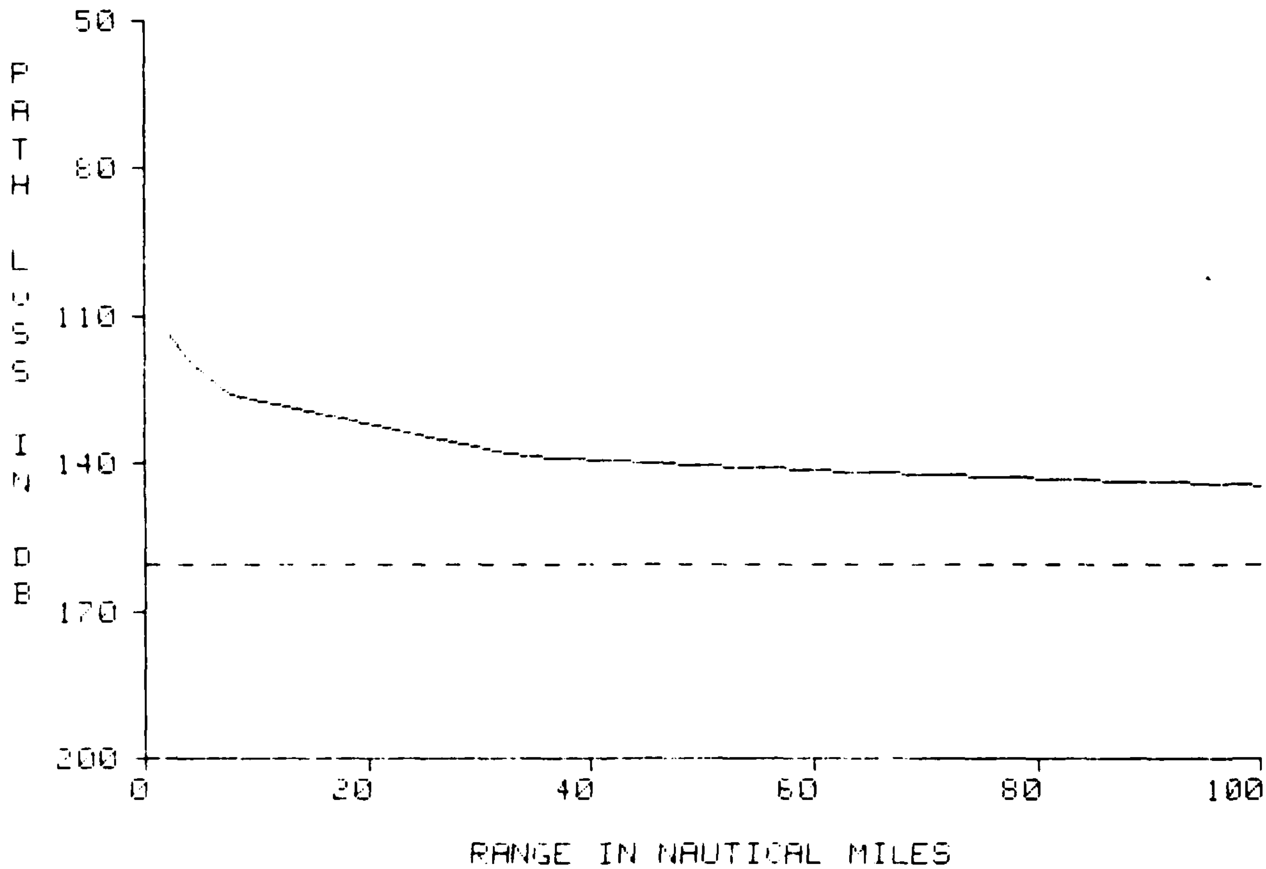
3.2.3 Horizontal Homogeneity

The IREPS program does not allow for horizontal changes in the refractivity structure. This restriction is not believed to be a serious one, since there exists scientific evidence

**** LOSS DISPLAY ****

SPS-10/DD

LOCATION: 31 56N 118 36W
DATE/TIME: 17 JUN 0045Z



SURFACE-SEARCH RADAR
FOR 50 % POD OF DESTROYER-SIZED SURFACE TARGET

DASHED LINE INDICATES DETECTION, COMMUNICATION, OR INTERCEPT THRESHOLD

FREE SPACE RANGE: 248.4 NAUTICAL MILES
FREQUENCY: 5600 MHZ
TRANSMITTER/RADAR HEIGHT: 160 FEET
RECEIVER/TARGET HEIGHT: 50 FEET

Figure 24. Loss product.

that the assumption of a horizontally homogeneous atmosphere is valid about 85 percent of the time for the purpose of making refractive effects assessments. The IREPS operator, and also the users of the IREPS products, should be aware of the changing state of the atmosphere and try to acquire and use refractivity measurements that are appropriate to the planned time and place of the pertinent operations.

3.2.4 Antenna Heights

The model that calculates the coverage display for surface-based systems is valid only for antenna heights between 3 and 250 ft. This should not be a restriction to any normal application for ship based systems, including submarines operating at periscope depth.

3.2.5 Interference Effects

The airborne coverage display model does not include sea-reflected interference effects which could cause both reduced and enhanced coverage for low-flying radar or target aircraft.

3.2.6 Polarization

The polarization of all the EM systems is assumed to be horizontal. Almost all radar systems are in fact horizontally polarized, so this limitation should be inconsequential to the radar case. However, some communications systems do employ vertical polarization and a small miscalculation in communication range could result.

3.2.7 Absorption

There is no account made of absorption from oxygen, water vapor, fog, rain, snow, or other particulate matter in the atmosphere. Most of these absorption effects are very minor over the valid frequency range of the models and will not affect the predicted ranges. For very heavy precipitation there may be a noticeable effect; but, even if the precipitation models existed, it would be difficult or impossible to obtain the required precipitation rates and horizontal extent from which calculations could be made.

3.2.8 Path Loss Plot Restrictions

The path loss plot does not include a model to account for propagation in an elevated duct. Also, the path loss plot does not include the interference nulls, but only gives a value in the interference region corresponding to the maximum signal (least loss).

3.3 SOME TACTICAL USES OF THE IREPS PRODUCTS

This section presents some of the tactical uses for the IREPS products as identified through actual fleet experiences. The section is not intended to be a complete list of uses since it is anticipated that many additional users of the products will be discovered as the interim IREPS becomes generally available on the carriers.

3.3.1 Aircraft Penetration Profile Determination

The standard procedure, for attack and reconnaissance aircraft, in penetrating an enemy target's defenses is to fly as low as possible to remain "beneath the radar coverage." This is valid during non-ducting conditions; however, surface-based ducting conditions often give the enemy a greater detection range capability for targets flying within the duct than with a target at high altitude. Knowledge of the existence and height of a surface-based duct would enable the strike group or aircraft commander to select the optimum altitude for penetration. This would be just above the top of the duct, where an absence of sufficient enemy radar energy exists for detection of targets. The coverage display geared to the adversary's air-search radar is the appropriate IREPS product to use in determining the optimum flight profile. For example, the best profile to avoid detection by the SPS-12, shown in figure 23, would be above the surface-based duct at an altitude of about 1500 ft. In this case, it would also be possible to avoid detection by flying down one of the interference nulls, but the changing height-versus-range profile would be more difficult to fly and if the aircraft were off course or the null pattern changed somewhat, detection would occur. At any rate, the worst place to fly would be at a few hundred ft above the sea, since detection here would occur at a greater range than at any other height.

3.3.2 Disposition of Forces

A knowledge of the presence or absence of surface-based ducting conditions gives the OTC a greater flexibility in deciding the disposition of his task force units. For example, if an OTC wishes to utilize a widely dispersed formation, yet maintain communications between units, he may do so under surface ducting conditions without the necessity of a middleman relay in the uhf communications link. The absence of ducting conditions dictates the use of a middleman. Knowledge of the presence of surface-based ducting also provides the possibility of uhf backup to over-the-horizon hf communications, ship-to-ship and ship-to-shore (i.e., CV to divert field). The path loss display, geared to uhf communications, is the proper IREPS product to use in assessing changes in refractive effects for such surface-to-surface applications.

3.3.3 ECM Aircraft Positioning

In a manner similar to that described in section 3.3.1, an ECM aircraft can adjust its position to maximize the effectiveness of its jammers by using the appropriate coverage display. Also, the range at which the jammers are effective can be considerably extended in the presence of ducting, which can give the ECM aircraft a much better stand-off capability and possibly allow jamming of more widely-spaced threats.

3.3.4 AEW Aircraft Stationing

By using the proper coverage displays, the optimum altitude for AEW aircraft can be determined, which will minimize the effects of radar holes created by elevated ducts. Figures 14 through 16 illustrated the various effects of stationing a typical AEW aircraft within, above, and below an elevated duct. Experience with these displays, for elevated ducts, shows that radar holes are minimized by flying as high above the duct as possible, or by flying anywhere below the duct.

3.3.5 EMCON Conditions

Emission control procedures are a primary tactical application of IREPS products. A knowledge of the existence of a strong surface-based duct is a warning that electromagnetic radiation will be trapped and result in enhanced signals. These can be intercepted at vastly greater ranges (hundreds of miles) than they can under normal conditions. Under ducting conditions, it would be prudent to weigh the benefits of the greatly increased radar search range against the much greater increase in the range a potential enemy gains for detection of the radiation. Even low power radiation sources, such as flight deck communications (Mickey Mouse) systems, have been intercepted at ranges greater than 200 nmi from the CV during ducting conditions.

Knowledge of the existence of ducting conditions enables a commander to maintain silence and detect an unsuspecting enemy hundreds of miles over the radar horizon through EW. Figure 21 showed the IREPS propagation conditions summary which would be most useful in determining EMCON conditions. In the case shown in figure 21, a strong surface-based duct exists to a height of about 1100 ft, causing greatly extended ranges at all frequencies. Under these conditions, the more prudent course of action may be to remain silent.

3.3.6 ASW Tactics

A direct tactical application of the knowledge of the presence of surface-based ducting conditions to communications procedures is found in the use of the multi-channel jezebel relay system (MCJR). An ASW helicopter engaged in dipping sonar operations over the line of sight horizon may relay to the ship while maintaining his sonar dip. This is especially important if he gains contact with a submarine and must both relay and maintain contact. If ducting conditions are present, the ASW helicopter knows that he can maintain both ASW surveillance and communications far beyond the normal radio horizon. If no surface-based duct exists, he must raise his sonar and increase altitude until he is within the horizon. In this case, a coverage display geared specifically to the MCJR would be used in assessing communications capability.

3.3.7 Uhf Communications

A coverage display for surface-to-air uhf communications can show the regions in space where communications are possible, considering the effects of the interference region and possible ducting. Independent of an aircraft's mission, it may be able to communicate to the ship by changing its altitude only slightly and exploiting the existing propagation effects. In this case it may even be advisable that the pilot have an IREPS hard copy of the appropriate uhf communications coverage display.

3.3.8 Hardware Performance Assessment

Knowledge of surface-based ducting provides for hardware performance assessment by sea going units. This phenomenon can explain detection of targets over the radar horizon on a given day and preclude unnecessary maintenance calls when similar ranges are not present during non-ducting conditions. False or "ghost" targets may also be a result of ducting conditions and are not always indicative of hardware problems. Coverage diagrams

may also be used to assess the performance of the various radars aboard a given unit, by providing a standard for optimum performance under non-ducting conditions and explain anomalies such as extended ranges and "radar holes" under ducting conditions.

3.4 OPERATING THE INTERIM IREPS

This section describes the operation of Interim IREPS which is a computer program that runs on a Hewlett-Packard 9845 desktop computer. Operation of the computer itself is described in appropriate HP manuals provided with the system. A general flow chart of the Interim IREPS operation is shown in figure 25.

3.4.1 How to Get Started

With the machine turned off, insert the IREPS tape into the right-hand tape drive, T15, and the DATA tape into the left-hand tape drive, T14. The tape cartridge must be inserted so that its label is up and its open edge is toward the computer. The tape drive window and the door below it will open when the cartridge presses on the lower door. Slide the cartridge fully into the slot. Notice that on each cartridge there is a black slide labeled RECORD. When this slide is to the left, data cannot be written onto the tape. Thus, on the DATA tape move the slide to the right (in the direction of the arrow). Otherwise, the program will indicate ERROR 83 whenever the operator tries to store data. In the case of the IREPS tape, it is advisable to leave the RECORD slide in the leftmost position to prevent accidental recording onto this tape.

Press the AUTOST key, located in the EDIT/SYSTEM FUNCTIONS section of the keyboard, into its down position and turn the machine on with the rocker switch located on the right-hand side of the computer below the T15 tape drive. The program will begin automatically and the screen display will be as shown in figure 26. Note that the revision number and date of the IREPS program tape is included in this display. Normally, the latest available revision of the tape is the one that should be used. The desired program name is entered via the keyboard and CONT (continue) is pressed. Then, follow the machine prompts, pressing CONT after each response to a prompt. Program options are described further in the following sections.

Alternatively, if the machine is already turned on, or was turned on without the AUTOST key in its down position, the program can be started from the keyboard by entering LOAD "AUTOST", 1 and pressing EXECUTE.

3.4.2 IREPS Program

3.4.2.1 Key Definitions. The first screen display that appears after selecting the IREPS program is shown in figure 27. These are the definitions assigned by the IREPS program to the special function keys in the upper right of the keyboard. The operators can use these keys to control program operation and screen display. (Note: the printout area of the screen can be controlled by the keys in the display section of the keyboard. These keys allow the operator to scroll the display if it is too large for the CRT. Refer to HP manuals for more details.) For convenience, the definitions should be abbreviated and written on a special function key overlay provided with the computer. The key definitions are mostly self explanatory and their use will become more evident as the operator gains familiarity

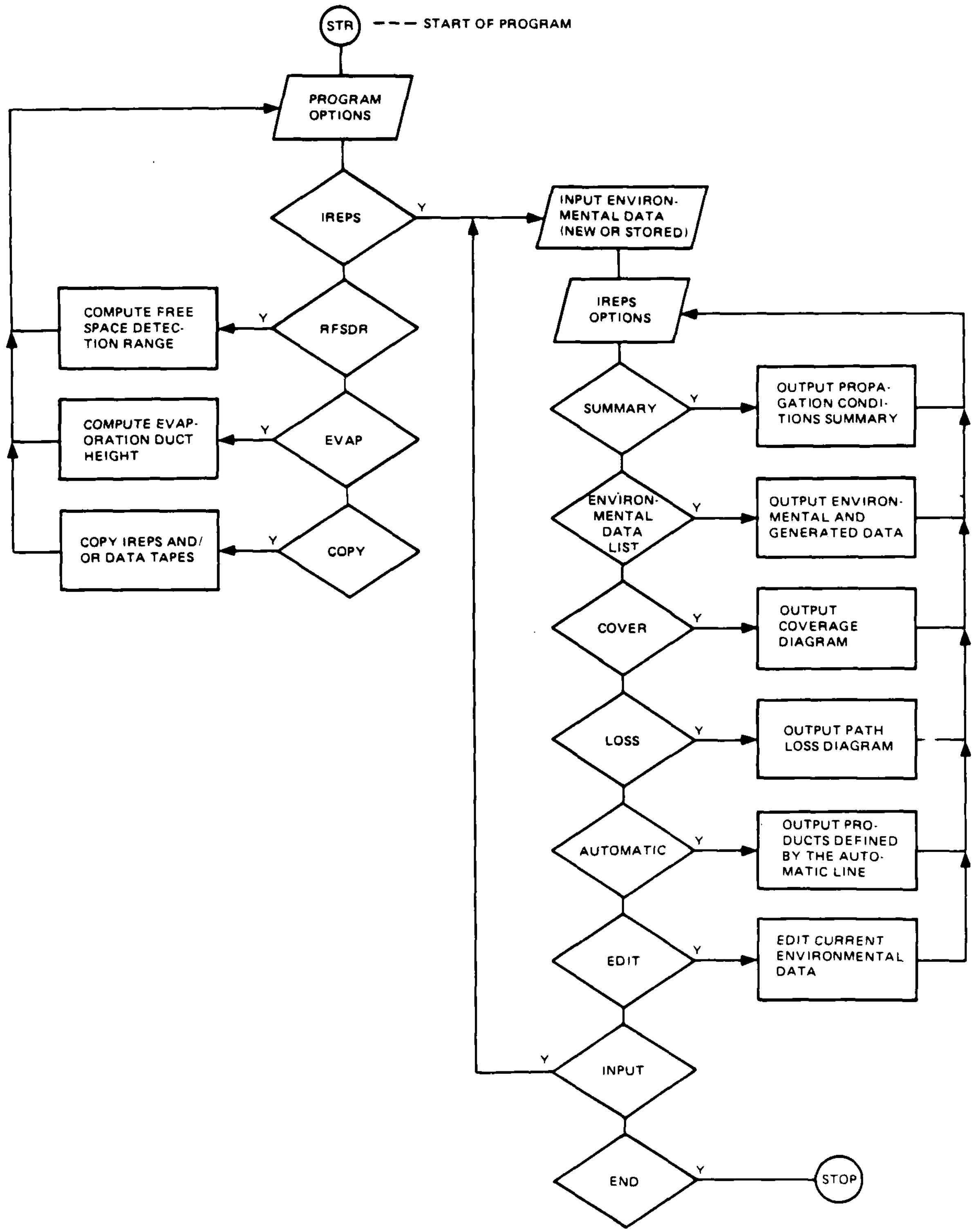


Figure 25. Top level flow chart of the interim IREPS program.

```
                                    IREPS TAPE (Rev. 1.4)  3/29/79

AVAILABLE PROGRAMS:

     IREPS.....Integrated Refractive Effects Prediction System
     RFSDR.....Radar Free Space Detection Range
     EVAP......Evaporation duct calculation
     COPY......Copy IREPS tape and/or IREPS DATA tape

Enter program desired (IREPS,RFSDR,EVAP,COPY)
```

Figure 26. Screen display of program options.

```
                           **** IREPS ****
        ** INTEGRATED REFRACTIVE EFFECTS PREDICTION SYSTEM **

   Note to the operator:
   The following user-keys will be in effect unless otherwise noted:
        KEY 'k0' will back up to the previous question.
        KEY 'k1' will immediately go to IREPS OPTION list
        KEY 'k2' will display printed output.
        KEY 'k3' will display plotted output.
        KEY 'k4' will disable internal printer.
        KEY 'k5' will enable internal printer.
        KEY 'k6' will rewind left hand tape.
        KEY 'k7' will rewind right hand tape.
        KEY 'k8' will repeat last output.
        KEY 'k9' following a 'STOP' will re_start this program.

        Pressing 'CONT' with no other entry will assign the first
          option in parentheses (or the first option in the list)
          as the desired option.
```

Figure 27. Screen display of IREPS special function key definitions.

with the IREPS program. A summary of the key definitions and an example overlay are shown in figure 28. The screen display is followed by the prompt to press CONT, to continue with the program.

3.4.2.2 Entering Environmental Data. The first step in using IREPS to assess refractive effects is to provide environmental data to the program. The program will indicate existing data sets as in figure 29. The operator must select the desired data set (select Ø to input new data; select 1-16 to recall previously stored data) and press CONT. If there are no existing data sets, only NEW will be indicated. The maximum number of data sets that can be stored is 16. Additional data can be stored only by replacing an existing data set.

The input routine for new data prompts the operator as to type of data to be entered: units of height, location, date/time, surface meteorological data, and sounding data. The types of data are radiosonde data, M-unit data, N-unit data, and coded WMO message data. The latter allows input of code groups representing significant level data of a sounding taken

SPECIAL FUNCTIONS

BACK-UP TO PREV. QUES.	GO TO IREPS OPTIONS LIST	ALPHA-NUMERIC DISPLAY	GRAPHICS DISPLAY	DISABLE PRINTER	ENABLE PRINTER	REWIND T14	REWIND T15
REPEAT LAST OUTPUT	RESTART	SAVE	STORE	EDIT	EDIT LINE	LIST	SCRATCH

Figure 28. Sample special function key overlay.

```
EXISTING ENVIRONMENTAL DATA SETS:

0  NEW
1  01 JAN 1120Z
2  01 JAN 2340Z
3  02 JAN 1135Z
4  02 JAN 2315Z
5  03 JAN 1110Z
        •
        •
        •

ENTER NUMBER OF DATA SET DESIRED
```

Figure 29. Screen display of environmental data sets.

at another location. The following is an example of data input (operator response is the second line of each set):

```
        ENVIRONMENTAL DATA FOR IREPS

TYPE OF DATA (RSONDE, M UNITS, N UNITS, WMO MSG)
RSONDE

UNITS OF HEIGHT (FEET,METRES)
FEET
```

```
LOCATION:
31 56N  118 36W

DATE/TIME:
17 JUN ØØ45Z

TRUE WIND SPEED IN KNOTS
12

EVAPORATION DUCT PARAMETERS (YES,NO)
YES

SEA TEMPERATURE (C)
18.2

AIR TEMPERATURE (C)
15.1

RELATIVE HUMIDITY (%)
89

RADIOSONDE LAUNCH HEIGHT ABOVE MSL (FT)
6Ø

STATION PRESSURE AT LAUNCH HEIGHT(MB)
1ØØ8.Ø

ENTER PRESS(MB), TEMP(C), REL HUM(%) FOR LEVEL 1
1ØØ8.Ø,15.1,89

ENTER PRESS(MB), TEMP(C), REL HUM(%) FOR LEVEL 2
1ØØØ,14.2,87

ENTER PRESS(MB), TEMP(C), REL HUM(%) FOR LEVEL 3 (OR END)
993,13.9,95

ENTER PRESS(MB), TEMP(C), REL HUM(%) FOR LEVEL 4 (OR END)
982,13.3,97

                              •
                              •
                              •

ENTER PRESS(MB), TEMP(C), REL HUM(%) FOR LEVEL 12 (OR END)
7ØØ,11.8,34

ENTER PRESS(MB), TEMP(C), REL HUM(%) FOR LEVEL 13 (OR END)
END
```

The sounding data is checked for consistency (i.e., pressures must decrease, heights must increase, and temperature and relative humidity must be within the ranges typical of the atmosphere). There must be at least two levels in the sounding. Additionally, with the exception of the profile data, IREPS will assign default values to the parameters indicated in the prompt if the operator presses CONT without entering any data. The default is the first parameter in a list (e.g., RSONDE is the default of RSONDE, M UNITS, N UNITS, WMO MSG), or some value specified by IREPS if there is no list (e.g., NOT SPECIFIED is the default for the prompt LOCATION).

Note that key kØ may be useful in entering new data when it is desired to backup and change a previous response. Corrections can also be made through the use of the EDIT function described later.

3.4.2.3 **IREPS Options.** The IREPS options (fig 30) are the various products available (1-4) and the functions that can be performed (5-8).

(a) SUMMARY is a plain language, descriptive summary of propagation conditions for surface-to-surface, surface-to-air, and air-to-air paths without reference to any particular system (fig 21). The appropriate setting of the refractivity adjustment on the SPS-48 is also indicated. This corrects for surface refractivity effects on the height-finding capability. The SUMMARY has applications for many varied users, among them the Task Group Commander, CIC, TSC, and airborne early warning, attack, and ECM squadrons. Note that key k8 can be used here to generate several copies.

(b) ENVIRONMENTAL DATA LIST is a listing of the environmental data, mainly for reference use by meteorological personnel. If the input data was a radiosonde profile, or WMO message code groups, the listing will be as shown in figure 22. If the input data was M or N units, the profile in the listing will show only level, height, M and N units, and refractive condition.

```
IREPS OPTIONS:
   1  SUMMARY
   2  ENVIRONMENTAL DATA LIST
   3  COVER
   4  LOSS
   5  AUTOMATIC
   6  EDIT
   7  INPUT
   8  END IREPS




ENTER OPTION DESIRED
```

Figure 30. Screen display of IREPS options list.

(c) COVER is a diagram of vertical coverage of a given radar (fig 23) based on system characteristics that have been entered into the systems library (discussed in section 3.5). This product is most applicable in assessing air search and early warning radar and uhf communications coverage. Potential users are CIC, TSC, and early warning squadrons with respect to their own radar coverage and attack and ECM squadrons with respect to enemy radar coverage.

(d) LOSS is a diagram of path loss versus range, for given atmospheric conditions and antenna heights (fig 24). The dashed line representing detection, communication, or intercept threshold is calculated from system performance characteristics. Whenever the path loss curve is less than the threshold (note that path loss increases downward on the ordinate), the target should be detected, communications should be possible, or intercept should be expected depending on the application.

(e) AUTOMATIC is a convenient option that automatically produces various IREPS products that have been previously defined by the operator. This option becomes useful once the routine users of IREPS products, and the type of products they can utilize, have been established. Creation/changing of automatic products is described in the next section.

(f) EDIT is an option that allows the operator to revise data or amend library contents. Figure 31 shows the edit functions that can be performed and the operator is requested to indicate which functions he desires:

> Line 1 allows the operator to edit the environmental data that is currently being used in producing IREPS products. Other data sets may be edited by selecting the appropriate data set under the INPUT option and then selecting the EDIT option.

```
LINE
  1   EDIT CURRENT ENVIRONMENTAL DATA
  2   DELETE AN ENVIRONMENTAL DATA SET FROM LIBRARY

  3   EDIT A SYSTEM
  4   INPUT A NEW SYSTEM
  5   DELETE A SYSTEM FROM LIBRARY

  6   LIST CURRENT AUTOMATIC LINE
  7   INPUT A NEW AUTOMATIC LINE




ENTER NUMBER OF LINE DESIRED.  (0 or END).
```

Figure 31. Screen display for EDIT option.

Line 2 allows the operator to delete existing data from the library. If the operator desires to have a record of this data, it should be listed to the printer by use of the ENVIRONMENTAL DATA LIST option before it is deleted.

Line 3 allows the operator to change performance parameters and display options of the systems currently in the library.

Line 4 allows the operator to input a new system. The machine lists existing systems and provides the prompts shown in figure 32. System parameters, i.e. antenna height, frequency, etc., may be available in radar handbooks or from the radar operator. For a complete definition of the system parameters see section 3.5. Free space range, for radar systems, can be calculated using the RFSDR program described later.

Line 5 allows the operator to delete systems from the library. The library holds a maximum of 32 systems.

Line 6 simply lists the products that are automatically outputted when the AUTOMATIC option is chosen.

Line 7 allows the operator to input an entirely new list of products for the AUTOMATIC option by following the machine prompts. The machine lists the systems in the library, and the display options, and then prompts the operator as to what IREPS displays (and in what quantities) will be in the new AUTOMATIC line. As an example of the questions asked of the operator:

```
DO YOU WANT TO PRINT ENVIRONMENTAL DATA?
(YES,NO)

DO YOU WANT A SUMMARY?  (YES,NO)

COVER DIAGRAMS:

1  ENTER NUMBER OF 'EXISTING SYSTEM' DESIRED FOR
   A COVER DIAGRAM.  (OR END)

LOSS DIAGRAMS:

2  ENTER NUMBER OF 'EXISTING SYSTEM' DESIRED FOR
   A LOSS DIAGRAM.  (OR END)
```

Exit EDIT by use of END. The machine will return to the IREPS OPTIONS list.

(g) INPUT is an option that allows the operator to go back to the environmental data library (see section 3.4.2.2) and access another profile or input a new one.

(h) END IREPS PROGRAM option is executed when the operator is finished. The two tapes are rewound and "good-bye" is displayed on the screen. The machine can then be shut off.

If the operator decides to continue running the program and the machine was not turned off after executing the END IREPS PROGRAM, he can press CONT which begins at the top of the last program option that was loaded or use the special function keys to initiate the program at another location.

```
Enter new system name.



DISPLAY OPTION      MAX. ALTITUDE        MAX. RANGE
       A            50,000 FT            200 NM
       B            25,000 FT            100 NM
       C            10,000 FT             50 NM
       D            20,000 M             400 KM
       E            10,000 M             200 KM
       F             5,000 M             100 KM
       G            USER REQUEST AT RUN TIME



ENTER DISPLAY OPTION DESIRED


TYPE OF PLATFORM IS (SURFACE OR AIRBORNE)

ENTER ANTENNA HEIGHT IN FEET

ENTER FREQUENCY (MHZ)

ENTER FREE SPACE RANGE IN NM

ENTER VERTICAL BEAMWIDTH IN DEGREES

ENTER ANTENNA ELEVATION ANGLE IN DEGREES

ENTER ANTENNA TYPE (OMNI,SINX/X,HEIGHT-FINDER,COSEC-SQUARE)

ENTER SECURITY CLASSIFICATION (UNCLASSIFED,CONFIDENTIAL,SECRET)

LABEL FOR SYSTEM (line 1):

LABEL FOR SYSTEM (line 2):
```

Figure 32. IREPS prompts for entering system parameters into the systems library.

3.4.3 RFSDR Program

The RFSDR program is used to calculate radar free space detection range (in nmi) to be used as an input to the system library in the IREPS program (see figure 33). Existing systems are listed for the operator. The operator then selects the desired system and follows the prompts for target size, probability of detection (.1, .25, .5, .75, or .9), probability of false alarms (10^{-4}, 10^{-6}, 10^{-8}, 10^{-10}, or 10^{-12}) and type of target (steady or fluctuating). Unless otherwise known, use a false alarm rate of 10^{-8} and a steady target for surface targets and a fluctuating target for air targets. The program then computes and displays the free space detection range. This information is noted and entered into the IREPS program by the operator when a system is created. Additionally, the operator can edit, delete, or add radar systems for the RFSDR program as desired. Note that the RFSDR systems library is separate from the IREPS systems library. To add a new radar, the operator needs to provide:

1) lower frequency in MHz
2) upper frequency in MHz
3) peak power in kW
4) pulse length in microsec
5) lower pulse rate in PPS
6) upper pulse rate in PPS
7) noise figure in dB
8) antenna gain in dB
9) horizontal beamwidth in deg
10) vertical beamwidth in deg
11) horizontal scan rate in RPM

```
RADAR: SPS-10
FREQUENCY RANGE IS 5450 TO 5825 MHZ
PEAK POWER IS 285 KW
PULSE LENGTH IS 1.3 MICROSEC
PULSE RATE IS 625 TO 650 PPS
NOISE FIGURE IS 14 DB
ANTENNA GAIN IS 32 DB
HORIZONTAL BEAM WIDTH IS 1.5 DEG
VERTICAL BEAM WIDTH IS 16 DEG
HORIZONTAL SCAN RATE IS 16 RPM
ASSUMED SYSTEM LOSSES IS 5 DB

TARGET SIZE = 35000 SQ. METRES
PROBABILITY OF DETECTION = .9
PROBABILITY OF FALSE ALARMS = 1E-08
TARGET IS 'STEADY'

FREE SPACE RANGE = 236.9 NM
```

Figure 33. Sample free space detection range calculation.

12) assumed system losses in dB

This information may be available in radar handbooks or from the radar operator. Assumed system losses are just that, an assumption. Reasonable values are from 5-12 dB.

3.4.4 Radar Cross Section

Radar cross section of a target is not necessarily directly related to the target's area. Yet, reasonably accurate cross sections are required to calculate free space detection range. Radar cross sections for various surface and airborne targets have been measured but these data are generally classified. However, the radar cross section of surface ship targets has been empirically related to radar frequency and ship displacement, and shown to be valid at several radar frequencies for ship sizes ranging from 2 000 to 17 000 tons displacement.[1] This relationship is:

$$\sigma = 52 f^{1/2} D^{3/2} \tag{5}$$

where, σ = radar cross section in square metres, f = radar frequency in megahertz, and D is ship's (full load) displacement in kilotons.

3.4.5 EVAP Program

The EVAP program is used when surface meteorological measurements are available but a sounding is not. The program requires true wind speed, air temperature, relative humidity, and an accurate measurement of sea surface temperature (see section 2.7.2). Duct height is calculated and displayed in metres.

3.4.6 COPY Program

COPY is used to copy IREPS or IREPS DATA tapes to blank tapes. Read the screen display very carefully and follow instructions to the letter! Remember that anything that is on the left hand tape, T14, will be overwritten and destroyed. The RECORD slide must be in the rightmost position on any tape inserted into the left hand tape drive.

3.5 DESCRIPTION OF THE SYSTEM PARAMETERS

When a system is created under the control of the EDIT option, a series of parameters must be supplied to IREPS that describe that system and the scales for the displays. The parameters are:

1) display option
2) type of platform
3) antenna height
4) frequency
5) free-space range
6) antenna type

---

[1] Skolnik, M. I., "An Empirical Formula for the Radar Cross Section of Ships at Grazing Incidence," IEEE Trans. Aero. and Elec. Sys., March 1974.

7) antenna beamwidth
8) antenna elevation angle
9) security classification
10) labels

This section will give a brief description of each of the above parameters.

3.5.1 The Display Option

The display option defines the maximum altitude and maximum range for the coverage display, or only the maximum range for the loss display when these products are requested for the subject system. The options are A through G, where each letter stands for the following combination of maximum altitude and maximum range.

Option	Maximum Altitude	Maximum Range
A	50 000 ft	200 nmi
B	25 000 ft	100 nmi
C	10 000 ft	50 nmi
D	20 km	400 km
E	10 km	200 km
F	5 km	100 km
G – Option A through F selected at time product requested		

Only the above options are allowed because of the severe distortion in the curved-earth coverage display that can result when other combinations of maximum altitudes and ranges are used.

3.5.2 Type of Platform

There are two options for the type of platform, namely SURFACE or AIRBORNE. SURFACE platforms are primarily those associated with shipboard systems, such as shipboard radars, communications, and EW systems. However, a surface system could be specified for any system with a transmitter or radar antenna height between 3 and 250 ft above sea level. The primary difference in the models is that calculations for the interference region are included for surface systems and are not included for airborne systems.

3.5.3 Antenna Height

If a surface system is specified, then an antenna height for the system must be entered. This antenna height must be between 3 and 250 ft. For airborne systems, the altitude of the aircraft will be entered at the time the coverage or loss display is requested.

3.5.4 Frequency

A frequency must be supplied for all systems. The limits are from 100 MHz to 20 000 MHz.

3.5.5 Free Space Range

This parameter is the most important parameter in properly assessing any system's performance. Since most IREPS applications have been for radar performance assessment, this parameter is usually the free space "detection" range, but it can easily be used for "communication" or "intercept" range for other applications. The parameter defines the range in free space conditions that the system can detect, communicate, or intercept and establishes a threshold for both the coverage and loss displays. In the case of the coverage display, the shaded area in the display will show the area that the system can detect or communicate under the existing conditions, if that same system can detect or communicate in free space at the free space range. For the loss display, this parameter establishes the dashed-line path loss threshold that corresponds to the free space path loss at the free space range. In either case, it can be considered as a "figure of merit" for the subject system. Special care must be exercised in determining the free space range for each application, or the resulting IREPS products will be misleading.

3.5.5.1 Establishing the Free Space Range for Radar Systems. There are two ways a free space detection range can be determined for radar systems. First, a theoretical calculation can be made based on the radar's performance parameters (transmitter power, antenna gain, noise figure of receiver, etc.) and an estimate of the target's size for given probabilities of detection, false alarm rates, and type of target. An independent program called RFSDR is included on the IREPS program tape to make these calculations and is briefly described in section 3.4.3. The other, often more accurate, method to establish the free space range is by observation of actual maximum detection range of known targets at angles above a few degrees where effects of refraction are minimized. In the case of surface radar systems, the free space detection range is one-half of the maximum observed range, because of the influences of the interference region. For airborne radar systems, the free space detection range is the maximum observed range.

3.5.5.2 Establishing the Free Space Range for Communications Systems. The best approach for establishing a free space communications range is by observation of maximum communications range at angles above a few degrees for surface-to-air or air-to-air communications. Often, uhf communications range is stated as "line of sight", but in reality, there must also be a maximum range within the line of sight based on transmitted power, receiver sensitivity, and the signal-to-noise ratio required to successfully communicate. For most uhf communications systems, this range seems to be about 100 to 200 nmi.

3.5.5.3 Establishing the Free Space Range for ESM Intercept. The free space range at which an ESM receiver can intercept a transmitter can be calculated using the following formula:

$$R = 10^{(10 \operatorname{Log}_{10} P - 20 \operatorname{Log}_{10} f + G - S + 22.2)/20} \tag{6}$$

where

R is the free space intercept range in nmi,

P is the transmitted power in kW,

f is the frequency in MHz,

G is the gain of the transmitter antenna in dB, and

S is the sensitivity of the receiver (including receiver antenna gain) in dBm.

These ranges can be extremely large, on the order of many thousands of nautical miles, which would truly be the ESM receiver's capability in free space. However, the influence of the earth and the other factors discussed in this document eventually limit the actual intercept range to a value much less than the free space intercept range. The path loss display is the proper display to use in assessing ESM intercept ranges and will set the dashed line path loss threshold properly, if the free space range based on equation (6) is entered when the system is created.

3.5.6 Antenna Type

There are four types of antenna that can be selected when creating a system. They are: omni, sin(x)/x, height-finder, and cosecant-squared. The antenna type that is selected dictates the amount of power radiated at varying elevation angles and can seriously affect the coverage or loss displays if wrongly selected.

The omni antenna is one that radiates uniformly in all directions. This type antenna is normally used with uhf communication systems where a whip antenna or a small aircraft mounted antenna is used. It can also be used on any system that is known to radiate nearly uniformly in all directions.

The sin(x)/x antenna is the most common type of directional antenna used by most surface-search and air-search radars. If nothing else is known about a system's antenna other than it is directional, then this antenna type would be the best to select.

The height-finder antenna type is used only with height-finder or three dimensional radars. In this type of radar, a narrow beam antenna is scanned vertically to determine target elevation angle and therefore, height.

The cosecant-squared antenna type is a special antenna type used in some air-search radars and airborne radars. This type of antenna should only be selected if it is known for certain that it is appropriate.

3.5.7 Antenna Beamwidth

For all the antenna types except the omni, an antenna beamwidth in degrees must be entered when creating the system. This beamwidth is the *vertical* beamwidth and describes the angle between the half-power points in the antenna pattern. An antenna with a 4 degree vertical beamwidth will radiate only half as much power, 2 degrees above and 2 degrees below the direction, of maximum power radiated. Normal values of beamwidth for the sin(x)/x antenna are from one degree, to 30 degrees. For a height-finder, the value is normally on the order of 1 degree and describes the width of the beam being scanned and not the entire composite pattern. For the cosecant-squared antenna, the beamwidth describes the angle up to which the pattern behaves like an omni antenna and is usually a value of 2 degrees or less.

3.5.8 Antenna Elevation Angle

For all the antenna types except the omni, an elevation angle in degrees must be entered that describes the direction of maximum power radiated by the antenna. This elevation angle is measured from the local horizontal (zero elevation angle) and increases in the upward direction. For most shipboard radars this angle will be zero. For many airborne radars this angle will be slightly downward (negative elevation angle). Except in special circumstances, the height-finder elevation angle will be zero.

3.5.9 Security Classification

The IREPS program will accept parameters for many different systems, some of which will be classified at differing levels. It is up to the operator to handle this classified material in a proper manner. As a convenience in labeling the products generated by IREPS, a security classification of UNCLASSIFIED, CONFIDENTIAL, or SECRET must be entered when creating a system. The coverage and loss displays will include a label of CONFIDENTIAL or SECRET on the product for those classifications. No classification label is generated for an UNCLASSIFIED system.

3.5.10 Labels

Two lines of labels, of up to eighty characters each, must be entered for each system. The operator can use these labels in any manner he wishes, but it is a good idea to at least describe the system and to define what the free space range is based upon.

3.6 WHAT TO DO ABOUT SOFTWARE OR MODEL PROBLEMS

There will undoubtedly be some cases where the validity of the IREPS products will appear questionable. If the problem cannot be resolved by checking the IREPS inputs and giving consideration to the limitations discussed in section 3.2, then send a copy of the product and the environmental data list, along with a list of the system parameters used, and a brief description of the problem to:

Commander (Attn: H. V. Hitney, Code 5325)
Naval Ocean Systems Center
San Diego, CA 92152

Also, any and all suggestions relating to IREPS, its models, displays, this manual, and tactical uses of the IREPS products are solicited and will be given due consideration.

3.7 WHAT TO DO ABOUT MAINTENANCE FOR THE HP 9845

The HP 9845s are all maintained by Hewlett-Packard on a world-wide in-port basis. If a problem should develop with the unit, the nearest Hewlett-Packard sales and service office should be called to arrange for repair. A list of all the offices world-wide with their phone numbers is listed near the back of the Operating and Programming manual. A copy of the service contract and service number will be provided with each unit.

INITIAL DISTRIBUTION LIST

CHIEF OF NAVAL OPERATIONS
NOP-952C
NOP-986G
NOP-987C

CHIEF OF NAVAL MATERIAL
NMAT-08T1
NMAT-08T116
NMAT-08T2
NMAT-08T245

NAVAL SEA SYSTEMS COMMAND
NSEA-03417

NAVAL AIR SYSTEMS COMMAND
NAIR-370C
NAIR-370G
NAIR-310B

NAVAL ELECTRONIC SYSTEMS COMMAND
PME-108

COMMANDER IN CHIEF US
ATLANTIC FLEET (N 37)
PACIFIC FLEET
O2M

COMMANDER SECOND FLEET
NSAP ADVISOR

COMMANDER THIRD FLEET
N33
NSAP ADVISOR

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AND EVALUATION FORCE
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MARINE CORPS DEVELOPMENT AND
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NSAP LAB REP

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CODE 3253

FLEET NUMERICAL WEATHER CENTRAL
COMMANDING OFFICER

NAVAL ENVIRONMENTAL PREDICTION
RESEARCH FACILITY
A WEINSTEIN

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NAVAL SURFACE WEAPONS CENTER
WD03 (NSAP DIRECTOR)
D-23

NAVAL WEAPONS CENTER
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D/812 (W HEILE)

NAVAL SHIP WEAPON SYSTEMS ENGINEERING STATION
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NAVAL WEAPONS ENGINEERING SUPPORT ACTIVITY
NWES-13

COMMANDER NAVAL OCEANOGRAPHY COMMAND

DEFENSE DOCUMENTATION CENTER (12)

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